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2
FORECASTING TRAFFICABILITY
OF SOILS

AIRPHOTO APPROACH



TECHNICAL MEMORANDUM NO. 3-331

Report 6

Volume I

June 1963

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U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

REPORTS OF THE SERIES ENTITLED "FORECASTING TRAFFICABILITY
OF SOILS" TECHNICAL MEMORANDUM NO. 3-331

<u>Report No.</u>	<u>Title</u>	<u>Date</u>
1	Meteorological and Soil Data, Vicksburg, Miss., 1948-1949	Oct. 1951
2	Meteorological and Soil Data, Vicksburg, Miss., 1949-1951	June 1952
3	The Development of Methods for Predicting Soil-moisture Content	Oct. 1954
4	Information for Predicting Moisture in the Surface Foot of Various Soils	Feb. 1957
5	Development and Testing of Some Average Relations for Predicting Soil Moisture	May 1959
6	Forecasting Trafficability of Soils; Airphoto Approach, Volumes 1 and 2	June 1963

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Report 6

Volume I

June 1963

**U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi**

ARMY-MRC VICKSBURG, MISS.

PREFACE

This report summarizes studies made by Purdue University under contract to the U. S. Army Engineer Waterways Experiment Station in regard to the use of airphoto interpretation techniques for estimating the trafficability of soils. This subject falls under Phase II of Task No. 1-T-O-21701-A-046-02, "Surface Mobility," of Department of the Army Project No. 1-T-O-21701-A-046, "Trafficability and Mobility Research." Phase II is concerned with the development of techniques for estimating the trafficability of soil and snow by noncontact means.

Phase I studies are concerned with estimating trafficability by contact means. They were begun in 1945 with emphasis on fine-grained soils because these soils constitute the gravest trafficability problems and are the most extensive type on the earth's surface, and were extended to include coarse-grained soils, especially sand beaches, in 1953, and snow in 1954. Satisfactory instruments and techniques have been developed for use in fine-grained soils and sand. Some work remains to be done in gravel and snow to complete basic research in Phase I. Phase I soil studies are described in the series of reports, Technical Memorandum No. 3-240, Trafficability of Soils. Studies in snow are reported in the series, Technical Memorandum No. 3-414, Trafficability of Snow.

Phase II studies are of two general types: one, a study of the use of aerial photographs for estimating trafficability; the other, a detailed study for predicting the effects of weather, physiography, soil properties, vegetation, and other physical phenomena on the trafficability of soil. The two studies, now being pursued almost independently, are meant to complement each other in the application stage.

The aerial photography study was performed under contract by Purdue University, Lafayette, Indiana. It was begun in 1949, when the District Engineer, St. Paul District, Corps of Engineers, requested personnel of the Airphoto Interpretation Laboratory, Engineering Experiment Station, Purdue University, to conduct a study of the feasibility of applying airphoto interpretation techniques to the prediction of soil trafficability. Work order No. 2 to Contract W-21-018-eng-683 was negotiated authorizing Purdue University to begin such a study as part of an overall task entitled "Trafficability of Soils as Related to Mobility of Military Vehicles."

Supervision of this contract was transferred from the St. Paul District to the Waterways Experiment Station in March 1951, to be continued until its expiration in June 1951. The study was continued by the Waterways Experiment Station after 5 June 1951 under the terms of Contract No. DA-22-079-eng-59 and was extended by work orders 1-16 until 30 June 1960.

Soil-weather studies have been in progress at the Waterways Experiment Station since 1948. In 1951, the U. S. Forest Service began working with the Corps of Engineers to develop a method for predicting soil moisture, the factor found to have the greatest influence on soil strength, and hence on soil trafficability. Studies have been conducted in a variety of climates, and work is in progress to develop a universal trafficability prediction method. Developments are reported in the series of reports entitled Forecasting Trafficability of Soils, Technical Memorandum No. 3-331, in which the present report is included.

Nine airphoto reports have been prepared by the Airphoto Interpretation Laboratory, School of Civil Engineering, Engineering Experiment Station, Purdue University, in cooperation with the Army Mobility Research Center (AMRC), Soils Division, U. S. Army Engineer Waterways Experiment Station, and given limited distribution. This report, the tenth, is a summary of these and will be given a much wider distribution.

Acknowledgment is made to the following personnel who participated in various phases of these studies or provided suggestions for or comments on the final report: Messrs. R. E. Frost,* O. W. Mintzer, III,*

* Presently not associated with Purdue University.

J. R. Shepard,* E. J. Yoder, J. G. Johnstone,* D. G. Shurig, and R. B. Johnson of Purdue University; and Messrs. S. J. Knight, A. A. Rula, and M. P. Meyer, AMRC. Special acknowledgment is made to Prof. K. B. Woods, Head, School of Civil Engineering, Purdue University, for advice and counsel, and to Mr. Warren E. Grabau, Chief, Area Evaluation Section, WES, for his suggestions and assistance in preparing sections of the final report. The report was written jointly by Prof. R. D. Miles, Airphoto Interpretation Laboratory, School of Civil Engineering, Purdue University, and Messrs. W. E. Grabau and A. A. Rula of the WES. All work was conducted under the general supervision of Mr. W. J. Turnbull, Chief, Soils Division, WES.

Directors of the Waterways Experiment Station during the conduct of this study and preparation of the reports were Col. H. J. Skidmore, CE, Col. C. H. Dunn, CE, Col. A. P. Rollins, Jr., CE, Col. E. H. Lang, CE, and Col. A. G. Sutton, Jr., CE. Technical Director was Mr. J. B. Tiffany.

* Ibid.

CONTENTS

	<u>Page</u>
PREFACE	111
SUMMARY	ix
PART I: INTRODUCTION	1
Purpose and Scope	1
Previous Airphoto-Trafficability Investigations by Other Agencies	2
Definitions	6
PART II: FACTORS AFFECTING TERRAIN TRAFFICABILITY	10
Soil Factors	10
Slope Factor	15
Obstacle Factors	16
Estimation of Trafficability	17
PART III: ELEMENTS OF PHOTO INTERPRETATION	19
Photo Elements	20
Terrain Elements	28
Elements Derived by Deduction	41
PART IV: CLASSIFICATION AND DESCRIPTION PROCEDURES FOR REPRESENTATIVE LANDSCAPES, AND AIRPHOTO INTERPRETATION AIDS	56
Classification of Representative Landscapes	56
Aids in Airphoto Interpretation	57
Procedure for Describing Representative Landscapes	58
PART V: LANDSCAPES IN UNCONSOLIDATED MATERIALS	59
Landscapes in Eolian Materials	59
Landscapes in Glacial Materials	68
Landscapes in Fluvial Materials	88
Landscapes in Lacustrine Deposits	116
Landscapes in Littoral Materials	124
Landscapes in Volcanic Deposits	130
PART VI: LANDSCAPES IN CONSOLIDATED MATERIALS	134
Landscapes of Low Relief in Horizontally Stratified, Sedimentary Rocks	135

CONTENTS

	<u>Page</u>
Landscapes of High Relief in Horizontally Stratified, Sedimentary Rocks	153
Landscapes in Inclined Stratified, Sedimentary Rocks	161
Landscapes in Igneous Rocks	176
Landscapes in Metamorphic Rocks	183
PART VII: PROCEDURES FOR AIRPHOTO ANALYSIS OF TRAFFICABILITY	190
Introduction	190
Analytic Procedure	191
PART VIII: EXAMPLE OF PHOTO INTERPRETATION	200
Step 1	200
Step 2	200
Step 3	200
Step 4	201
Step 5	201
Step 6	202
Step 7	203
Steps 8 and 9	203
Step 10	205
Steps 11, 12, and 13	207
Step 14	209
Step 15	210
Step 16	211
Steps 17, 18, and 19	211
Step 20	214
Step 21	214
PART IX: CONCLUSIONS AND RECOMMENDATIONS	215
BIBLIOGRAPHY	216
TABLES 1-12	
FIGS. 1-67	
APPENDIX A: INDEX TO GEOGRAPHIC LOCATION OF ALL TRAFFICABILITY TEST AREAS	
FIG. A1	
APPENDIX B: SUMMARY OF SOIL AND SITE DATA	
APPENDIX C: GENERALIZED LANDSCAPE-PARENT MATERIAL MAPS	
FIGS. C1-C9	

Note: Tables 1-12, figs. 1-67, Appendix A and fig. A1, Appendix B, and Appendix C and figs. C1-C9 are presented in Volume II of this report.

SUMMARY

The study reported herein is part of a comprehensive effort, begun in 1949, to develop techniques for estimating the trafficability of soil by remote means. It is devoted specifically to development of techniques for analyzing and interpreting vertical aerial photographs for soil trafficability purposes. To provide a basis for this study, airphoto and soil trafficability data were collected over a period of several years by Purdue University and Waterways Experiment Station personnel from 33 humid-climate states and 2 arid-climate states in the United States. This report describes the principles and procedures of airphoto interpretation required to estimate the trafficability of soils, and summarizes data reported previously in supplemental reports in a form suitable for use by personnel engaged in airphoto-trafficability analyses.

Soil factors, slope factors, and obstacle factors, all pertinent to terrain trafficability, are discussed. Terrain is classified into various representative landscapes which are fully described in regard to regional drainage, topography, local erosion, natural vegetation, cultural practices, parent material, soil profile, and trafficability and cross-country movement characteristics. Procedures for airphoto analysis of trafficability are rigidly defined, and an example of photo interpretation is given.

It is recommended that:

- a. Future effort include the development of a system of terminology for describing surface configuration in a fashion suitable for photo interpretation.
- b. Further study be made of the nature and type of information that can be derived from a photograph alone.
- c. A major effort be made to quantify terrain descriptions, especially descriptions of the surface configuration.
- d. A determined effort be made to develop a site classification system for photo interpretation, especially with respect to soil moisture.
- e. A soils classification system specifically for trafficability purposes be developed.
- f. Study be devoted to the development of a regional concept suitable for trafficability purposes.

Solution of the problems represented by these recommendations will result in a substantial increase in the effectiveness of photo interpretation for trafficability purposes. Further, it would lead to important advances in precision in all fields in which photo interpretation is used as an important data source.

Three appendices are included. Appendix A lists the locations in which the soil and trafficability tests of this study were conducted. Appendix B presents a summary of the soil and site data obtained from these tests. Appendix C comprises nine generalized landscape-parent material maps, showing worldwide geographic occurrence of each representative landscape type.

FORECASTING TRAFFICABILITY OF SOILS

AIRPHOTO APPROACH

PART I: INTRODUCTION

Purpose and Scope

1. The study reported herein is part of a comprehensive effort, begun in 1949, to develop techniques for estimating the trafficability of soil by remote means. It is devoted specifically to development of techniques for analyzing and interpreting vertical aerial photographs for soil trafficability purposes; to assist in this analysis certain airphoto and soil trafficability data were collected over a period of several years by Purdue University and Waterways Experiment Station personnel and are included herein.

2. This report describes the principles and procedures of airphoto interpretation required to estimate the trafficability of soils occurring primarily in temperate climates of the continental United States. It summarizes the data reported previously in a series of nine reports in a form suitable for use by personnel engaged in airphoto-trafficability analyses. The earlier reports, issued under the general title Forecasting the Trafficability of Soils, Airphoto Approach, are listed below.

Report 1, Application of Airphoto Pattern Analysis to Soil Trafficability Studies, June 1951.

Report 2, Glacial Patterns, June 1951.

Report 3, Water Deposited Patterns, 1st ed., June 1951.

Report 4, Miscellaneous Patterns, June 1951.

Report 5, Wind Deposited Patterns, November 1953.

Report 6, Residual Patterns, June 1954.

Report 7, Water Deposited, Residual, and Glacial Patterns, September 1956.

Report 8, Techniques for Predicting Soil Trafficability Information from Aerial Photographs, September 1956.

Report 9, Glacial Deposited Materials, December 1957.

3. The above-listed reports contain detailed data on soil

trafficability for various landscape-parent material combinations. These data were obtained in humid climates in 33 states and arid climates in 2 states of the United States. Topographic high and low locations and, in some cases, an intermediate or slope location were tested at each test site to determine soil classification and strength (as described in Part II). Where possible, these locations were tested during both wet and dry seasons to establish the range of seasonal trafficability conditions. A total of 550 locations were tested at 191 sites. Appendix A lists each location at which tests were conducted, and the data collected are summarized in Appendix B.*

Previous Airphoto-Trafficability Investigations by Other Agencies

4. Previous work in airphoto interpretation of trafficability has been devoted primarily to the compilation of representative aerial photographic patterns of soil-parent material areas and keys for use in interpreting terrain features. A brief review of the studies in this field pertaining to soil trafficability follows.

Purdue University studies

5. Mr. J. R. Shepard, as a part of his graduate work at Purdue University, reported on a study undertaken to correlate soil trafficability data obtained at selected field sites with airphoto patterns.^{18**} The airphotos, taken about 10 years earlier, were used to study parent material airphoto patterns and variations in the airphoto pattern due to topography and drainage. Trafficability field data collected over a period of a year were presented for selected soils developed from glacial drift and alluvial materials. Generalized correlation between trafficability conditions measured in the field and features observed on the airphotos was reported. Valuable field data were obtained on seasonal variations in soil trafficability.

6. Major R. E. Clark, Corps of Engineers, conducted a study to predict trafficability conditions of the Big Delta area in Alaska by means of

* Appendices A, B, and C are presented in Volume II of this report.

** Raised numerals refer to similarly numbered items in the Bibliography at end of text.

aerial photographs as part of his graduate work.⁵ He prepared a soils map and deduced seasonal trafficability conditions from photographs and literature of the area. Three trafficability maps were prepared presenting trafficability conditions for the winter, spring, and summer seasons. Ratings of good, fair, poor, and bad were assigned various areas, depending upon the inferred ability of a medium tank to traverse the areas. Field tests were conducted in Alaska to verify predicted conditions, and fairly good agreement was reported.¹

7. Captain D. D. Litt, United States Air Force, during his graduate work analyzed and classified 24 landforms in terms of soil trafficability.¹⁵ He suggested that a system of seven climatic regions subdivided by landform types lends itself to the compilation of photo interpretation keys for use in tactical and strategic military studies. His inferences on soil trafficability were based on a study of the landforms from airphotos and a knowledge of soil characteristics obtained from a survey of the literature and correlation with topographic positions observed on the photos. No field data on performance of vehicles and no measured field trafficability data pertaining to the various landforms were presented in the report.

8. Mr. A. G. Altschaeffl, as a part of his graduate work, reported on a study to correlate the variability of soil moisture with densitometric readings of the gray tones of airphoto negatives.² In test areas devoid of vegetation, he reported that, for the limited data available, 30 to 60% of the variation in transmission density readings on aerial negatives could be attributed to variations in soil moisture content.

Cornell University studies

9. Cornell University conducted a study on beach trafficability for the Office of Naval Research. The results of the study have been compiled into a three-volume report on beach types and their interpretation from aerial photographs.⁶ A tentative procedure for making photo-intelligence estimates of beach trafficability is included. Special photographs were taken and vehicle tests conducted in conjunction with the research program.

10. In addition to the photo analysis keys developed for beaches, Cornell University has developed and published a set of interpretation keys for various landform types.⁷ The Cornell landform study differs from the

Purdue study reported herein in that correlations between measured trafficability data and specific airphoto patterns are not attempted in the Cornell reports except for the beach study.

Military Geology Branch,
U. S. Geological Survey, studies

11. The Military Geology Branch, USGS, is composed of a group of geologists, geographers, soil scientists, and botanists who are responsible for preparation of terrain studies of strategic areas. They evaluate terrain by studying topographic maps, land-use maps, geology maps, soil survey maps, and aerial photographs.¹⁴ The airphotos are used to study vegetation, obstacles, slopes, drainage conditions, man-made features, and other conditions not portrayed on a map. The terrain studies are prepared for both strategic and tactical levels of command. Map scales vary from 1:10,000 to 1:1,000,000 or smaller. Cartographic limitations restrict the amount of information that can be placed on a map; therefore, legends and text are used to explain localized variations in trafficability which may be caused by weather and microrelief features. Reference 13 is an example of a terrain study.

German World War II studies

12. Several foreign countries use aerial photographs to augment basic map data and to assist in the preparation of terrain studies. The German army during World War II had special teams of scientists organized to make terrain studies. The composition of these teams was similar to that found in the organizations functioning at various levels in the Department of Defense, Corps of Engineers, and Geological Survey of the United States.⁴ The German teams differed in that they operated mainly at the tactical level (during the African campaign). Documents indicate that the terrain studies were beneficial in planning military operations. Details of the extent to which photographs were used and the procedures followed were not available for presentation in this report.

Norfolk County, East
Anglia, England, study

13. At the request of the Office, Chief of Engineers, the Waterways Experiment Station and Purdue University cooperated to produce in September 1952 a terrain study of a foreign area under simulated emergency conditions

for the British Joint Services Mission.¹² The area studied was located in Norfolk County, East Anglia, a few miles north of the city of Norwich, England. Long focal length (24- and 36-in.) aerial photographs at a scale of approximately 1:15,000 were supplied along with topographic maps of 1:63,360 scale and a general glacial drift map at 1:23,400 scale. The airphotos covered an area of about 300 square miles.

14. Two studies were performed. One consisted of using all available personnel to conduct the study in a total elapsed time of 72 hours. The other was a 6-week study using various airphoto experts. Each study required the preparation, at a scale of 1:63,360, of a cross-country movement overlay, a soils overlay, and an airfield suitability overlay, with descriptive legends and accompanying text.¹²

15. The team that conducted the test was composed of civil engineers, geologists, and assistants who had some experience (from 1 to 10 years) in the use of aerial photographs for interpreting soil conditions. None of the team members had ever visited the area or had prior knowledge of it.

16. The British Royal Engineers assigned a five-man field crew to conduct a ground survey of the area and to prepare a report evaluating the photo interpretation study.⁸ Soil samples obtained in the field were classified in terms of the Unified Soil Classification System (USCS).²⁰ Soils identified from aerial photographs in the airphoto study were described in terms of an engineering-geologic classification. The correlation of the geologic system with a restrictive soil classification system proved difficult. A photo interpreter views the soil from several thousand feet, and often the soil is masked by vegetation so that deduction of the soil type must be based on geological and ecological conditions. Although it was possible in this study to estimate the soil texture because of certain geological features in evidence within the area, the estimate was necessarily general. The engineering soil classification was determined by laboratory analysis of each sample. Laboratory analysis did not always confirm "predicted" soil type.

17. The general conclusion of the personnel who conducted the field study was that the 6-week study had an average 72% accuracy and the 72-hour study an average 60% accuracy in correctly predicting soil conditions.

WES studies

18. The Waterways Experiment Station conducted a trafficability survey in which a trafficability map of selected areas of Camp Stewart, Ga., was prepared.²² Geologic maps and literature, aerial photographs and reconnaissance, topographic maps, interrogation, field sampling, ground reconnaissance, and tank (M48) traffic tests provided data for the trafficability analysis. Information from the various sources was studied simultaneously to develop relations of soils, topography, vegetation, and land use to trafficability. This was accomplished by first selecting a terrain type which appeared to repeat itself many times in one of the major landforms identified at Camp Stewart. The terrain types were determined from a study of topographic maps and aerial photographs. The terrain types were examined at several locations in the field; terrain data and soil strength (rating cone index) measurements were obtained. The field data indicated a certain consistency of trafficability conditions within each terrain type. Once a trafficability rating was assigned to each terrain type within a given landform, all similar terrain types appearing on the aerial photographs were assigned the same trafficability rating. Trafficability maps were prepared representing trafficability conditions for an area of 152 square miles at a scale of 1:25,000 for the wet and dry season conditions. Four ratings were assigned to the areas surveyed depending upon the ability of the area to support an M48 medium tank on the basis of year-round movement. Following the completion of the study, the trafficability of many of the mapped areas was checked with M48 tanks, and excellent agreement was found between the tank performance and the trafficability indicated on the map.

Definitions

19. Certain words and terms are used in this report in restrictive connotations. They are defined below. For certain of these, conventional abbreviations are used as indicated in parentheses following the term.

Soil terms

Soil. Unconsolidated organic or inorganic materials on the surface of the earth. In this report, the term is restricted to the pedological

soil (i.e. the A and B horizons), or when such a distinction cannot be made, the upper 18 in. of the unconsolidated material is considered.

Fine-grained soil. A soil of which more than 50% of the grains, by weight, will pass a No. 200 sieve (smaller than 0.074 mm in diameter).

Coarse-grained soil. A soil of which 50% or more of the grains, by weight, will be retained on a No. 200 sieve.

Sand. A coarse-grained soil with the greater percentage of the coarse fraction (larger than 0.074 mm) passing the No. 4 sieve (4.76 mm).

Sand with fines, poorly drained. A sand in which the fines (smaller than 0.074 mm) impede internal drainage.

Trafficability terms

Critical layer. The layer of soil regarded as being most pertinent to establishing relations between soil strength and vehicle performance. For freely draining or clean sands, this is usually the 0- to 6-in. layer. In fine-grained soils and sands with fines, poorly drained, it is usually the 6- to 12-in. layer. However, the critical layer may vary with weight of vehicle and soil strength profile.

Terrain trafficability. The ability of terrain to permit the movement of a military vehicle. It includes the sum of the effects of soil (or snow) properties, slopes, surface roughness, and obstacles of all types.

Soil trafficability. The ability of a soil on a level or sloping surface to permit the movement of a military vehicle.

Strength terms

Cone index (CI). An index of the shearing resistance of soil obtained with the cone penetrometer (see page 8). The cone index is a dimensionless number representing the resistance to penetration into the soil of a 30-degree cone with a 1/2-sq-in. area (actually load in pounds on cone base area in square inches).

Remolding index (RI). A ratio that expresses the change in strength of a fine-grained soil or a sand with fines, poorly drained, that may occur under traffic of a vehicle.

Rating cone index (RCI). The product of the measured cone index and remolding index for the critical layer of soil. This index is valid only for fine-grained soils and for sands with fines, poorly drained.

Vehicle terms

Vehicle cone index (VCI). The minimum rating cone index of the soil that will permit the vehicle to complete 50 passes traveling in a straight-line path on a level surface.

Mobility index (MI). A dimensionless number obtained by applying certain characteristics of the vehicle²² in an empirical formula. The mobility index has a definite relation to the vehicle cone index requirements.

Instrument and equipment terms

Cone penetrometer. A field instrument consisting of a 36-in. shaft with a 30-degree cone of 1/2-sq-in. base area mounted on one end and a proving ring with dial gage and handle mounted on the other end. The force required to move the cone at a rate of approximately 6 ft per min through a plane of a given material is indicated on the dial inside the proving ring. This force is considered to be an index of the shearing resistance of the penetrated material and is called the cone index of the material in that plane. A capacity load of 150 lb deflects the ring 0.1 in. and gives a cone index reading of 300.

Trafficability sampler. A piston-type soil sampler for securing soft soil samples. Spacer bars permit cutting the sample to such a length that the density of the soil in pounds per cubic foot may be obtained by multiplying the weight of the sample in grams by 0.4.

Remolding equipment. A cylinder of the same diameter as the trafficability sampler cylinder mounted vertically on a base, and a 2-1/2-lb drop hammer which travels 12 in. on an 18-in. section of a cone penetrometer shaft fitted with a circular foot. A cone penetrometer equipped with a 1/2-sq-in. base area cone, and a trafficability sampler are used to conduct a remolding test.

Remolding tests

100-blow remolding test. This test is used to determine the remolding index of fine-grained soils, and is conducted in the following manner: A sample is taken with the trafficability sampler, loaded into the remolding cylinder, and pushed to the bottom with the drop hammer. Cone indexes are measured at the surface of the soil and at 1-in. vertical increments to a depth of 4 in. Next, 100 blows of the hammer are applied and cone

indexes are remeasured in the remolded soil. The remolding index is the sum of the five cone index readings made after remolding (a value of 300 is assigned to each depth that cannot be penetrated) divided by the sum of the five readings made before remolding.

Vibrated remolding test. This test is used to determine the remolding index of sand with fines, poorly drained, and is conducted in the same manner as the 100-blow test, with two exceptions. The cone index measurements are made with the 0.2-sq-in. cone instead of the 0.5-sq-in. cone, and the sample is remolded by placing the soil sample in the remolding cylinder and dropping the cylinder loaded with the soil sample by hand 25 times from a height of 6 in.

PART II: FACTORS AFFECTING TERRAIN TRAFFICABILITY

20. Terrain trafficability is affected by all physical components of the natural and cultural environment. It is affected by the geometry of the surface, by the soils and rocks composing that surface, by the vegetation cover, by surface-water and groundwater conditions, and by all forms of cultural modifications. Cultural modifications include features developed as a result of particular land-use practices, such as terracing, contour plowing, irrigation, drainage, etc., as well as those resulting from construction, such as roads, walls, embankments, etc.

21. While all attributes of the landscape (that portion of the terrain that can be viewed from an observation point) must be examined if its trafficability is to be established, the most fundamental component is the nature and condition of the soil. Because slope is an integral attribute of the soil, vehicular movement must be considered in terms of the effects of both soil and slope.

22. Vehicle movement is also affected by obstacles; therefore, obstacles such as vegetation and various cultural features must be evaluated. The obstacle factor also includes those slopes which exceed the maximum a vehicle can climb. Cultural modifications of the landscape are commonly of considerable importance, not only because many of them are obstacles, but also because they may affect soil strength by altering the natural conditions of the soil. For example, such land-use practices as contour plowing, irrigation, or drainage may alter the soil moisture and/or the soil structure, which in turn may alter soil strength.

Soil Factors

Soil strength

23. The ability of a soil to support a load or to resist tractive forces is primarily a function of its shear strength. Shear strength in coarse-grained soils is primarily a function of frictional resistance between soil grains, which in turn depends upon the intergranular pressure and the angle of internal friction. However, in fine-grained soils, or coarse-grained soils containing fines, the factors affecting shear strength

are far more complex. Shear strength of fine-grained soil depends not only upon frictional resistance, but also upon cohesion between soil particles. The factors contributing to cohesion are not entirely understood²⁵ but are known to include the void ratio, structure (i.e. the geometric relations of soil particles to their neighbors), the size, shape, and crystalline type of the grains, and various forms of molecular and/or electromagnetic attractions and repulsions. Soil moisture is also effective in producing changes in frictional and cohesive soil properties, and thus changes in soil strength. Soil strength may also vary with the stress history of the soil, and may be materially decreased or increased by remolding (i.e. disturbance).

24. Seasonal effects may also impose significant effects on the state-of-the-ground. In northern latitudes soft soil areas may freeze deep and hard enough to support most vehicles during the winter season. At the same time these areas may be covered with a mantle of soft, deep snow introducing a new terrain surface that becomes impassable for wheeled vehicles when the snow depth approaches approximately 25% of the wheel diameter. During the spring breakup, soils that are normally trafficable when wet may become untrafficable for short periods as a result of an overabundance of water released from snow and ground ice melt. Although data for this report were collected in areas where seasonal freeze-thaw occurs, data were usually collected after the soils had thawed completely. Consequently, data are not available to quantify soil trafficability for such seasonal conditions. Because of the significance of freeze-thaw condition to soil trafficability, special studies are being conducted to relate soil, site, and climatic factors with freeze-thaw ground conditions.

Equipment used to measure soil strength for trafficability purposes

25. For trafficability purposes the cone penetrometer is used for measuring soil strength. In general, the cone index (CI) of the soil layer between the 0- and 6-in. depths is critical for most military vehicles operating in clean sands (SP), and the soil layer between the 6- and 12-in. depths is critical for most military vehicles operating in fine-grained soils and sands with fines, poorly drained. The range of CI's for fine-grained soils and sands with fines, poorly drained (i.e. before-remolding

strength, see paragraph 26), of maximum interest is that between 30 and 200. A few special vehicles, such as the weasel, otter, and snowmobile, can traverse areas in which the CI for the critical layer in these soils is as low as 30; when the CI is below this value, even these vehicles are immobilized. On the other hand, only a few special vehicles with very high contact pressures require a CI greater than 200. These limits usually make it possible to classify large land areas as above or below the critical range. Tracked vehicles usually experience little or no difficulty in traveling on clean sands. However, a wide range in wheeled-vehicle performance on such sands occurs as a result of changes in tire pressure; at low tire pressure a significant increase in performance is obtained.

26. In fine-grained soils and sands with fines, poorly drained, the CI serves to classify the trafficability of a soil only before remolding. It is, therefore, inadequate for predicting the strength of a soil during or after repeated passage of a vehicle, because these passages invariably remold the soil, thereby altering its strength. The probable effect of vehicular traffic on soil strength is predicted by the standard remolding test outlined on page 8. From this test a factor, the remolding index (RI), is obtained that indicates the direction and magnitude of strength change that can be anticipated under vehicular traffic. For example, a silt when wet may retain only 20% of its undisturbed strength when subjected to repetitive vehicular traffic. The trafficability of a soil is defined in terms of a value called the rating cone index (RCI) which is the product of the CI and the RI for the same soil layer. In terms of RCI, the range of maximum interest in trafficability studies is that from 15 to 100. In clean sands a remolding test is not required and CI only is used to define trafficability. Vehicle tests in sands have indicated that the first pass is the most critical and that subsequent passes are made with less difficulty.

Evaluation of soil trafficability

27. The ability of a vehicle of a specific type to complete 50 passes in the same path across a level area or to execute severe maneuvering in fine-grained soils or sands with fines, poorly drained, is assured if the RCI of the soil in the critical layer in that area is greater than the vehicle cone index (VCI) assigned to that vehicle.²³ In general, an

RCI equal to 75% of the VCI indicates adequate soil strength to permit one or two straight-line passes of the vehicle. The VCI's for most military vehicles are tabulated in Appendix A, 14th Supplement, TM 3-240. It is possible to compute a mobility index (paragraph 126, 14th Supplement) for vehicles not tabulated, and relate it to VCI (plate 13, 14th Supplement). The VCI's tabulated are restricted to vehicles operating in fine-grained soils or sands with fines, poorly drained. For convenience in classifying vehicle performance in fine-grained soils and sands with fines, poorly drained, military vehicles have been grouped in terms of their VCI's in the following tabulation. Each category shown identifies, in effect, the minimum soil strengths required for operation of the vehicles in that category. Studies conducted on clean sands have not yet progressed to the point of quantifying trafficability. The results of these studies are reported in reports of the series entitled "Trafficability of Soils," TM 3-240, Supplements 13, 15, and 17.

<u>Category</u>	<u>VCI Range</u>	<u>Vehicles</u>
1	20-29	M29 weasel, M76 otter, and Canadian snowmobile are the only known military vehicles in this category
2	30-49	Engineer and hi-speed tractors with comparatively wide tracks and low contact pressures
3	50-59	Tractors with average contact pressures, tanks with comparatively low contact pressures, and some trailed vehicles with very low contact pressures
4	60-69	Most medium tanks, tractors with high contact pressures, and all-wheel-drive trucks and trailed vehicles with low contact pressures
5	70-79	Most all-wheel-drive trucks, a great number of trailed vehicles, and heavy tanks
6	80-99	A great number of all-wheel-drive and rear-wheel-drive trucks, and trailed vehicles intended primarily for highway use
7	100 or greater	Rear-wheel-drive vehicles and others that generally are not expected to operate off roads, especially in wet soils

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4	60-69	Most medium tanks, tractors with high contact pressures, and all-wheel-drive trucks and trailed vehicles with low contact pressures
5	70-79	Most all-wheel-drive trucks, a great number of trailed vehicles, and heavy tanks
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7	100 or greater	Rear-wheel-drive vehicles and others that generally are not expected to operate off roads, especially in wet soils

28. As an example of the use of the system, assume a fine-grained soil or a sand with fines, poorly drained, with a CI of 100 and an RI of 0.49. The RCI is then 49 ($RCI = CI \times RI = 100 \times 0.49$). With the requirement that the RCI be greater than the VCI, all vehicles in categories 1 and 2 would be able to negotiate the soil in question.

29. From the preceding discussion it is apparent that the RCI is actually an integration of all factors affecting soil strength into a single value that has been especially derived to correlate with soil trafficability.

Classification of soils

30. The capability of estimating soil strength from values of such discrete soil properties as texture, moisture content, plasticity, organic matter content, and density is materially improved by categorizing the soil in terms of one of the several existing systems of soil classification. Such systems are founded upon specific combinations of values of properties, or upon well-defined indexes which are themselves integrations of several fundamental properties.

31. Unified Soil Classification System. The system used extensively by the Corps of Engineers is the Unified Soil Classification System (USCS).²⁰ It differentiates soil groups on the basis of texture, plasticity, and relative amount of organic material, and is outlined in table 1.*

32. USDA soil textural classification. Another system, widely used by both agricultural soil scientists and civil engineers,^{16,27} is that of the United States Department of Agriculture (USDA). This system is primarily based on grain sizes or the relative proportions of the sand, silt, and clay fractions, each term being defined as a specific range of sizes. The USDA textural triangle used to classify soils is shown in fig. 1.*

33. Comparison of USCS and USDA systems. Both classification systems are useful for the purpose of evaluating the trafficability of soils because they tend to arrange soils into categories of similar strength. However, because the classification systems are based on somewhat different criteria, the soil types within the two systems are not entirely correlative. Table 2 shows the frequency of USDA soil types occurring as USCS

* Tables 1-12 and figs. 1-67 are presented in Volume II of this report.

soil types. It is to be noted that each USDA soil type occurs as more than one USCS soil type (and vice versa). For example, the 481 silt loam (SiL) samples actually appear as seven USCS types; however, more SiL samples (215, or 45% of the total number of SiL samples) appeared in the lean clay (CL) type than in any of the other USCS types.

34. Soil trafficability classification. The process of soil classification has been carried a step further by development of a scheme for the special purpose of evaluating soils for trafficability purposes. This scheme, called the Soil Trafficability Classification (STC), assembles USCS soil types into four categories designated A, B, C, and D on the basis of similarity of RCI obtained during the wet season. An additional category, E, was established so that peat and muck soils could be included. A summary of this system and the general trafficability characteristics of USCS soils during the wet season is presented in table 3. A more sophisticated scheme for classifying soils from a trafficability standpoint is described in TM 3-240, 16th Supplement; however, the one presented herein is considered adequate for the purpose.

35. The major problem in forecasting soil trafficability by means of airphotos is the establishment of the soil type. This cannot be done directly; instead, the type must be deduced from the photographic evidence of soil type together with such related features as drainage, vegetation, and topography and from "background information" on climate and geological and cultural history of the area. In general, the accumulation of such knowledge does not result in a direct deduction of soil type; rather, it results in estimates of fundamental soil properties such as texture, soil moisture, plasticity, density, and internal drainage. With such information the soil can then be fitted into an existing classification, and the interpretive chain thus completed. Evidence must therefore be sought on aerial photos that will allow estimates to be made of fundamental soil properties. This process is examined in detail in Part III.

Slope Factor

36. Because vehicular movement is affected not only by soil strength, but also by the slope on which the soil occurs, any estimation of the

terrain trafficability must incorporate an evaluation of the effects of slope. Slopes too steep for the vehicle to climb constitute a complete barrier to vehicular movement; however, this is only the most obvious of the effects. A more subtle effect becomes evident when one examines the problem posed by a vehicle attempting to climb a slope composed of a soil whose strength is close to that which is critical for that vehicle. Empirical criteria have been developed for estimating the effect of slope on vehicle performance. In fine-grained soils the maximum slope negotiable for approximately 50 passes by a given vehicle is determined by subtracting the VCI from the RCI of the soil in question, and relating this excess (by means of the procedures outlined in the 14th Supplement, TM 3-240) to the vehicle characteristics. For example, in a fine-grained soil with an RCI of 70, the M46 medium tank with a VCI of 60 (Appendix A, 14th Supplement, TM 3-240) could negotiate a maximum slope of 23% with the excess of 10 points in soil strength. The RCI requirements for vehicles with towed loads negotiating slopes are explained in paragraph 119, 14th Supplement, TM 3-240. In the 17th Supplement, TM 3-240, CI is related to maximum slope negotiable for tracked and wheeled vehicles on sand. The effect of tire pressure on slope-climbing ability is also shown.

37. The relative direction at which a slope is negotiated must also be considered. The angle of movement of the vehicle with respect to the strike of the slope dictates the magnitude of the forces being applied by the vehicle to the soil surface. For example, the downslope track or wheel has a greater load applied than the upslope, and as a result, deeper rutting occurs on the downslope side. This increases the effective slope. In some cases, this may impede or even prevent turning; it may overturn the vehicle, or immobilize it because of increased rolling resistance.

Obstacle Factors

38. In general, there are four elements (in addition to slopes too steep to climb) of the landscape that produce obstacles to movement. These are: surface irregularities (commonly called microrelief), vegetation, hydrologic occurrences, and cultural phenomena.

Surface irregularities

39. A surface irregularity is considered to be an object or

configuration of the surface that is of such magnitude as to interfere with vehicular movement. Examples include boulders such as are found in many deserts and glaciated regions, potholes, streambeds, and hummocks such as are commonly found in portions of the arctic.

Vegetation

40. In many parts of the world plants grow so large and close together as to make vehicular movement impossible. However, even when trees are so spaced that movement between them is possible, the necessary maneuvering may severely impede forward progress, not only because of the increased path length, but also because turning forces exert a higher load on the soil than those generated in straight-line movement. Thus, the soil strength requirements for a given vehicle are greater when the vehicle is maneuvering than when it is traveling in a straight line.

Hydrologic factors

41. As used in this report, a hydrologic factor is any body of surface water. Such features constitute obstacles to movement whenever the water becomes deep enough or turbulent enough to threaten the safety or operation of vehicles.

Cultural factors

42. Cultural factors of the terrain that would impede vehicle travel or necessitate maneuvering include items such as walls, hedgerows, ditches, dikes, embankments, etc.

Estimation of Trafficability

43. From the discussion in the preceding paragraphs it is clear that the determination of the trafficability of an area from aerial photos must be a step-by-step progression through successive stages. The obstacle factors previously described, in most instances, can be deduced from the aerial photographs. In some areas obstacles occur in combinations, and it may be difficult to accurately assess their trafficability significance. For example, vegetal cover may make it impossible to examine surface irregularities and hydrologic factors. The final estimate of soil trafficability is an estimate of the area's RCI. Because this value cannot be estimated directly from aerial photos, it must be deduced from other

evidence. In general, the process is to first establish the soil type (as categorized by either the USCS or USDA), which then permits an estimate to be made of the CI and RI, which in turn yields the final product, the RCI.

PART III: ELEMENTS OF PHOTO INTERPRETATION

44. An aerial photograph, vertical or oblique, is a perspective representation of a segment of the surface of the earth. It is not a true orthographic projection of the terrain for it does not portray each image as if viewed directly from above. However, by the use of proper equipment and techniques a wealth of terrain information can be obtained from aerial photographs. The techniques used in obtaining such data are:

- a. Photogrammetric technique or the science of measuring horizontal and vertical distances from photography. This can be complemented with selected ground control, and used in the compilation of maps.
- b. Photo interpretation technique or the art of analyzing the features of the terrain as recorded on the aerial photograph and, by deductive reasoning, determining their effect upon a particular problem.

45. The two techniques are supplementary and interdependent; therefore, the photo interpreter must have a knowledge of both. However, it is beyond the scope of this report to present the entire spectrum of photogrammetric techniques. Several manuals presenting this material are available.¹⁰

46. In the use of aerial photographs for soil trafficability studies, the interpreter is interested in all the environmental characteristics that are recorded or can be inferred. Because the environmental characteristics include almost the gamut of the physical sciences, the interpreter must have an understanding of the basic concepts of climatology, geomorphology, geology, pedology, geography, ecology, hydrology, and civil engineering. For this reason teams of scientists and engineers trained in photo interpretation are best qualified to make airphoto trafficability studies.

47. The photo interpretation technique is based on three fundamental assumptions:

- a. The aerial photograph is a record of the results of longtime natural and man-made processes which are reflected on the photograph as surface features.
- b. The surface features on the airphoto can be grouped together to form patterns that are characteristic of particular environmental conditions.
- c. The environmental conditions and their reflected airphoto

patterns are repetitive; that is, similar environments will produce similar airphoto patterns while different environments will usually produce different airphoto patterns.

48. The terrain elements that collectively produce patterns on aerial photographs include the topography (geometry of the surface), regional drainage, local erosion, vegetation, and cultural features. All of these elements are essentially interrelated, but in this study, as in most airphoto interpretation studies, they have been arbitrarily separated in accordance with a classification designed to facilitate description, analysis, and evaluation for trafficability purposes.

49. However, before attempting to interpret terrain, the interpreter must know something of the properties inherent in the photographs themselves. For this reason, the following discussion has been divided into three sections, the first of which is an outline of the properties of photographs per se, the second an outline of those fundamental terrain conditions and properties that result in distinctive visual airphoto patterns, and the third an outline of elements derived by deduction.

Photo Elements

50. The aerial photo, used as a record of surface conditions, is created by certain spectra of light energy producing the photo image being reflected (or emitted) from the surface of objects. A panchromatic photo records the surface only as tones of gray, and not, as does the human eye, in tones of gray and variations of color. Thus, two widely different colors which would be readily differentiated by the human eye may have exactly the same gray tone on a photograph. In addition, the photo is a much-reduced image of the actual situation; that is, it is a scaled representation. Accordingly, familiar pattern elements may become so reduced in size as to present an unfamiliar appearance on an aerial photograph; for example, the familiar linear pattern of a plowed field becomes an even gray without perceptible pattern when the scale of the photo is very small. Also, variations in processing, as well as in atmospheric conditions, light source, and other factors, may so alter the appearance of familiar objects as to make them difficult to recognize.

51. In general, there are three basic properties of photographs:

- a. Photo tone, which is the variation in tones of gray on a photograph.
- b. Photo texture, which is the combination of tones of gray on an exceedingly small scale, such that individual features are close to the limit of resolution, but in which an overall pattern of variation can still be detected.
- c. Photo scale or the ratio of distances on the image relative to correlative distances on the surface of the ground.

Tone

52. Photo tone responds to variations in a wide range of factors. Many of these are not related to surface conditions, which makes it imperative that the interpreter understand and compensate for these variations.

53. Reflectance geometry. One factor that produces endless variation is the reflectance geometry (i.e. the relation between light source, reflecting surface, and camera). Because of this factor, tone in a given area may change from flight line to flight line, even from photograph to photograph, because in each successive exposure the light from any given point is reflected to the camera at a slightly different angle. As an extreme example of the effect of this factor, a freshly plowed field in cohesive soil might photograph either very light or very dark, depending upon the reflectance geometry. When the light is received by the camera primarily from the "polished" side of the spoil ridges, the photo tone might be light gray; when it is received from the tumbled and crumbly face, the photo tone might be dark gray. The angle of incidence of the light also affects the reflectance angle, and thus may also produce this effect. Although the effect is not so pronounced in vertical photos, it is still important, especially when the sun is close to the horizon either because of time of day or latitude. A variation of this condition occurs with topographic position, as a result of complete or partial shadowing. For example, one side of a hill may photograph dark and the other side light, despite the fact that surface conditions are identical.

54. Photo processing effects. Photo processing also affects photo tone. Even minor changes in developing time, developer usage, printing exposure, and developer temperature can produce wide ranges in the tones

of a given point. Normally such changes can be recognized because the overall tone of the photo becomes darker or lighter.

55. Altitude effects. The altitude at which a photograph is taken also affects tone. In general, the higher the altitude the lighter will be the tone. This effect is produced by the increasing atmospheric scattering of light with altitude.

56. Surface property effects. Despite the variations in tone produced by reflectance geometry, processing, and altitude, the properties of the ground surface itself produce the major differences in tone. In general, the conditions resulting in tone variation are differences in (a) the texture of materials, (b) water content of surface materials, and (c) the intrinsic colors of materials. Color in this instance is assumed to include not only hue but chroma (i.e. purity or saturation) and value (i.e. brightness). All variations in tone not ascribable to reflectance geometry, development variations, and altitude can result from combinations of texture, water content, and color variables.

57. Generalizations as to the effect on the airphoto image of these fundamental variables are very difficult to make, because they invariably occur as combinations, and in many situations any one can completely mask the effect of the others. In general these variables affect the photo tone as follows:

- a. The finer the grain size, the lighter the tone. Tone is the result of the sum of the reflectance from all surfaces; a large proportion of the total area of very fine-grained materials is composed of reflecting surfaces.
- b. The higher the moisture content, the darker the tone. Water readily absorbs light energy, and reflects very little.
- c. The darker the color of the soil or rock (i.e. the value), the darker the photo tone.

58. In practice, not only can any one of the variables mask all the others but other factors, normally much less important, may dominate because of a special combination of conditions. As a result, the photo interpreter should never use only the generalizations cited in paragraph 57 above; they must always be leavened with knowledge of the possible effects of subsidiary conditions. The following examples illustrate this point:

- a. Coarse-grained soils commonly photograph light gray, while fine-grained soils photograph medium or dark gray. This reversal of the principle stated in paragraph 57a results from a complex of conditions. First, the water-retention ability of fine-grained soils tends to maintain soil moisture at a higher level; thus, the ability of water to absorb light energy results in a tendency to darken the tone of fine-grained soils. Second, coarse-grained soils are commonly light colored, because the weather-resistant minerals of which they are composed tend to be light colored. Third, fine-grained soils tend to have slightly higher organic contents, resulting in a still further darkening of the soil color. Extremely organic soils, such as mucks and peats, commonly photograph nearly black.
- b. The intrinsic color of bare rock commonly dominates the other factors. Limestones, which may be both fine grained and light colored, tend to photograph light gray. Other light-colored rocks which tend to photograph in light tones include granites and acidic lavas, such as rhyolites and andesites. Shales tend to photograph medium gray, although numerous exceptions occur. Sandstone, a rock type which varies widely in both color and texture, is equally variable in photo tone, ranging in general from light to medium gray. Basic lavas, such as basalts, or other igneous rocks composed primarily of dark-colored minerals, tend to photograph dark gray when weathered, and almost black when fresh. Metamorphic rocks cover virtually the entire spectrum of colors and textures, and as a result the photo tone of this group is also highly variable.
- c. Intrinsic color and texture combine to make vegetation tones exceedingly variable. In general, coniferous stands tend to photograph dark gray, hardwoods light to medium gray, and green grasses or crops dark to medium gray. These tendencies are altered by seasonal variations in color and density.
- d. Cultural practices produce striking tone variations. For example, freshly plowed fields almost invariably photograph darker than untilled fields, because the plowing brings subsoil moisture to the surface (see fig. 2). (A notable exception in which reflectance geometry reversed the normal tendency is outlined in paragraph 53.) Fig. 2 also illustrates variations in tone caused by variations in soil moisture and organic content in plowed fields. The light gray portions of the field are drier and contain less organic material than the irregular dark gray areas. Distinct changes in photo tones occurring along irregular lines in contrast to regular lines of field patterns usually reflect variations in the texture and moisture content of the soil.
- e. Although open water normally photographs dark, it may in some instances be the lightest area on the photograph. This may occur when the reflectance angle is close to the angle

of total reflection; in this case, the water body may photograph as a brilliant flare of white. Water discolored by heavy loads of silts, clays, or chemicals may also photograph light to medium gray.

Texture

59. There is no clear line of demarcation between photo tone and photo texture, nor is there one between texture and pattern. Photo texture is a pattern produced by innumerable repetitions of very tiny features, each of which has a distinct appearance. When these features become so small that the camera and film combination will no longer resolve them, the texture vanishes and the area becomes a single tone of gray. For example, the fields in photo b of fig. 3 display a distinctly linear and rather "tweedy" texture at a scale of 1:2400, while the same fields, as shown in photo a of fig. 3, are reduced to nearly uniform gray at a scale of 1:30,000.

60. Variations in photo texture are difficult to classify, and even more difficult to describe adequately. However, for this report five fundamental distinctions have been made, although it must be understood that they grade into each other. These are (a) linear textures, in which the sense impression is one of closely spaced parallel lines; (b) botryoidal, in which the sense impression is one of randomly arranged hemispheres of mixed sizes; (c) flecked, in which the sense impression is one of an even surface of variable tones; (d) mottled, in which the impression is one of a spotty surface of variable tones; and (e) smooth, in which the impression is one of an even and featureless surface.

61. Linear. Cultivation very commonly results in distinctly linear photo textures. Row crops, such as corn, beans, or truck crops, produce very markedly linear textures. For example, see photo b of fig. 4. (The arrows on the photographs on the left in figs. 4 and 5 indicate the direction in which the ground photograph on the right was taken.) Crops that more nearly cover the entire ground surface display less obvious linear texture and may in fact approach or even achieve a smooth texture. For example, the photo texture of the field shown in photo a of fig. 5 is almost completely smooth while that in photo d of fig. 5 is faintly linear. The furrows thrown up by plows or disks commonly photograph with a linear texture; faint linear traces remain even after the fields have been

harrowed. For example, even the smoothed fields illustrated in photos a and c of fig. 4 reveal faint traces of linear textures.

62. Botryoidal. Forests, especially of broadleaf trees, photograph with a botryoidal texture. The wooded areas in fig. 7 illustrate this texture. It is occasionally produced by other vegetation types, such as bunch- and hummock-forming grasses, but in such cases the texture is finer for comparable scales. The botryoidal texture rarely occurs without the presence of vegetation, but it does occasionally result from certain types of surface conditions. Notable examples are certain types of lava flows.

63. Flecked. Flecked textures occur because of a wide variety of conditions, and are consequently represented by a broad range of variations. Variable thickness of grass cover or pasture lands produce this texture, an example of which occurs in the open field at the upper middle of fig. 6. It may be also produced by crop stubble as in photo c of fig. 5. This texture is also produced by certain types of surface configurations; any combination of circumstances that produces randomly arranged flecks of either light or dark against an otherwise uniform background will result in this texture. It is commonly superimposed on linear textures to produce a "tweed" appearance, such as the left central field in photo b of fig. 4.

64. Mottled. Mottled textures are very common. It is, in fact, difficult to find a photograph without some trace of mottling. Normally, in vertical photographs it is produced directly by variations in soil moisture, color, or grain size, and indirectly by vegetative difference induced by such variations. For example, every photograph in fig. 5 displays mottled textures to some extent. It should be noted that the elements composing the mottled textures are large in comparison to those composing the other textures. They are, in fact, so large that they can be classed as patterns, in the same sense as drainageways form patterns.

65. Smooth. Smooth textures are produced by featureless surfaces. Surfaces that usually photograph as featureless are water surfaces without wave action, snow, and bare sand areas that have not been eroded by the wind. All textures that can be identified on large-scale vertical photographs can become smooth-textured if the photo scale is reduced to the point where the identifiable feature can no longer be resolved.

Scale

66. The scale of a photograph largely controls the amount of detail exhibited. This factor does not necessarily militate against small-scale photography; some aspects of terrain are best determined from small scales, while others are best obtained from large scales. In general, large scales provide minute details of pattern, tone, and texture; but regional impressions are lost. For example, it may be very difficult to determine the regional drainage pattern from a set of large-scale photos, even though it is detectable at a glance from a single small-scale photograph. Other factors also require consideration; for instance, the physical problem of handling the large numbers of individual prints required to cover an area at very large scale may be substantial.

67. Requirements for trafficability estimations. Trafficability estimations commonly require detailed information such as can only be obtained from large-scale photos. As a result of this conflict with the advantages of small-scale photos, it is desirable in trafficability studies to work with two or more scales. For example, a set at very large scales (e.g. 200 to 400 ft to the inch; one flight path will cover a width of 1800 to 3600 ft on the ground if the standard 9- by 9-in. photograph is used) with which to study specific routes, and another set at small scale (e.g. 1000 ft to the inch, or even 5000 ft to the inch) with which to study regional implications.

68. Scale ratio and scale factor. The photo interpreter should obviously be familiar with the basic geometry of scale variations, as well as the significance of such changes from an interpretive viewpoint. The scale of a photograph is a function of camera focal length and flight height above average ground elevation, and is expressed thus:

$$\text{Scale ratio} = S = \frac{f}{12H} \left(\frac{\text{in.}}{\text{in.}} \right)$$

$$\text{Scale factor} = S_f = \frac{H}{f} \left(\frac{\text{ft}}{\text{in.}} \right)$$

where f is the focal length in inches, and H is the height above mean ground level in feet.

69. Correlation of photo scale and number of prints required. The

following tabulation shows the relation between contact photo scale and number of 9- by 9-in. photographs required (60% overlap between successive photos in the same flight path, and 30% sidelap between adjacent flight lines) for a 10-mile route-of-approach and for an area of 56 square miles (approximately a 7-1/2-minute topographic quadrangle).

Scale Ratio	Scale Factor ft/in.	Area per Photo sq miles	Theoretical Number of Photographs Required for a Given Area	
			10-mile Route-of- Approach	7- by 8- mile Area
1/40,000	3330	32.32	7	18
1/30,000	2500	18.18	8	28
1/20,000	1667	8.08	11	45
1/10,000	834	2.02	20	128
1/5,000	417	0.50	37	450
1/2,500	208	0.13	73	1652

70. Photo limitations. Because an aerial photograph is a perspective projection, perspective layover (i.e. the apparent tendency of vertical-standing objects to radiate from the center of projection) and exaggeration of the vertical dimension occur. Perspective layover is troublesome in areas of great local relief, such as mountains, or cities with tall buildings, because it is difficult to achieve a true visualization of the surface configuration. Vertical exaggeration is troublesome because it is virtually impossible to visually estimate vertical heights and angles. As a result, the interpreter should always base slope and height estimations on actual values as measured photogrammetrically (see paragraphs 44 and 45), rather than on a purely visual estimate.

71. Vertical exaggeration varies inversely with the focal length if the scale is constant, i.e. the shorter the focal length the greater the vertical exaggeration. For example, in fig. 8 the buildings and trees appear to be taller and the ditch deeper on the 6-in. focal length picture than on the 12-in. focal length picture. Because terrain interpretations commonly depend on relatively small differences in relief, it is normally useful to have photographs with a substantial amount of vertical exaggeration. Such photographs make it easier to evaluate subtle differences in relief. Therefore, in most instances photos obtained with cameras of

focal lengths of about 6 in. are preferable for trafficability studies, though 8-1/4- and 12-in. focal length pictures are generally adequate.

Terrain Elements

72. Terrain elements are those features, attributes, and materials composing a landscape. For purposes of systematic and reasonably objective description, each fundamental component of the landscape must be classified in consistent and rigorously definable terms. In this report, the fundamental components of a landscape are considered to be regional drainage, topography, local erosion, natural vegetation, the works of man, parent materials, and soils.

73. The topography (i.e. the geometry of the earth's surface) is primarily the result of the interaction of erosional and depositional agents, the nature of the rocks and soils, the structure of the earth's crust, the climatic regime, the vegetation, and the works of man. The topographic surface is, in effect, a synthesis of all environmental elements into a single expression. As such, it plays an important role in the evaluation of an area for trafficability purposes, because it provides a key for deducing the properties and processes at work in the region.

74. The topographic surface is composed of two fundamental elements: the plan arrangement and the cross-sectional shape. The plan arrangement of topographic surfaces is produced by the arrangement of terrain elements of different elevations (i.e. the topographic highs and lows) with respect to each other. The cross-sectional shape is the figure that would be in evidence if, for example, a topographic high was sliced vertically from crest to drainageway on either side.

75. In general, the plan arrangement of the topographic surface is most readily defined in terms of the regional drainage pattern, because the drainageways automatically define the low topographic positions, and the higher topographic positions must necessarily occupy the spaces between. For this, a fundamental classification of regional drainage types is necessary. The classification used in this report is given in table 4, and discussed in paragraphs 78 through 83. It should be noted that the term "drainageway" is used in a special sense in this classification.

76. The cross-sectional shape of the topographic highs and lows, although infinitely variable, can nevertheless be classified into fundamental types or forms. Such a classification is discussed in paragraphs 84 through 88.

77. A region is any area which is characterized by repetitive features at the scale of examination. For example, on photographs at small scale, an area might display only two detectably different patterns as the result of differences in landscape features. On this scale, only two regions could be delineated because such regions can be established only on recognizable distinctions. However, when large-scale photographs of the same area are examined, it might be found that additional patterns become evident. Thus, each of the two original regions might be subdivided into secondary regions. This sliding scale of definition can theoretically be carried to the maximum level of detail that is significant for the purpose at hand. There is accordingly no quantitative implication as to the size of the area defined by the term region.

Regional drainage

78. Major drainage patterns. Major drainage patterns (i.e. regional drainage) are the result of either present or past erosion or deposition. These patterns serve to subdivide areas into regions throughout which the plan arrangements of features are essentially similar. As used in this report, regional drainage is not intended to imply that water will be found in the drainageways at all times or even at any time. For example, many areas of fixed dunes exhibit no drainage pattern in the classical sense of a pattern of scoured channels. However, the dune hollows (the topographic lows) may exhibit trafficability conditions substantially different from the dunes (the topographic highs), and this difference is generally either directly or indirectly related to drainage conditions. Further, a region of this type can be clearly differentiated from other regions on the basis of its drainage (or lack thereof). Thus, for trafficability purposes, the airphoto pattern for such a region can be regarded as a regional drainage pattern, despite the fact that it is without surface drainage. Further, the regional drainage has no connotation of specific areal limits, being equally as effective in subdividing a small area as in subdividing a large one.

79. Specific drainage patterns. Specific regional drainage patterns are in general produced by certain specific combinations of conditions, or factors. The number of interrelated factors makes it inevitable that the use of regional drainage to deduce such conditions as soil type will be subject to many ambiguities. Thus, the drainage pattern should never be used alone. However, when used in conjunction with other attributes of the landscape, it can be of inestimable assistance in the identification of specific trafficability conditions.

80. Classification of drainage patterns. Many attempts have been made to classify regional drainage patterns. Probably the most thorough system is that of Parvis,¹⁷ an adaptation of which is illustrated in fig. 9, and which is described in table 4. Like the shapes of uplands, stream patterns are infinitely variable. Thus although the types are easy to identify in their extreme (i.e. "type") form, they grade into each other in so complex a fashion that countless "borderline" cases occur. Nevertheless, when they can be identified, they constitute an invaluable tool in the hands of the photo interpreter. Accordingly, table 4 has been prepared to assist in the identification of various drainage patterns and features.

81. It should be noted that two major considerations in the interpretation of drainage patterns are not incorporated in the definitions in table 4 per se. The first of these is the fact that a single drainage system may display several drainage types simultaneously. For example, the gross drainage pattern of a region may be dendritic, while the low-order stream patterns (see fig. 10 for illustration and definition of ordering) may be pinnate. This situation is very common in areas of deep loess, for example. In this connection, it is principally the low-order drainageways that are affected by those considerations which are of greatest interest to the trafficability analyst; namely, the type and structure of the parent materials, and the soil types. High-order streams are generally much less delicately controlled by subtle variations in parent materials and soils, and are therefore much less useful to the trafficability analyst. In general, streams of greater than about order 4 tend to lose trafficability significance, although there are many exceptions to this generalization.

82. When drainage patterns are being studied, the types should be established by tracing out the scour and swale channels, down to and

including the gullies. The gullies then become first-order streams. The patterns formed by the gullies and the next two or three orders into which they drain are collectively called low-order drainage patterns in this report. If the gullies and very low-order streams are not considered, the resulting patterns are called gross drainage patterns in this report.

83. The second basic consideration is that neither the description in table 4 nor the illustrations in fig. 9 contain any implication of scale. This is because nature places no specific limitations on the size of the specific types of drainage patterns. For example, the distributary type may be found displayed in the "deltas" formed at the margins of puddles after rain, but they also occur over hundreds of square miles in such places as Louisiana or Egypt, with all intermediate sizes represented elsewhere. In general, it is the pattern that counts, and not the scale.

Topography

84. Topography or the cross-sectional shape of the uplands can be fully appreciated only by stereoscopic examination of airphotos. Furthermore, size and the angles of component slopes are commonly necessary for adequate interpretation; therefore, the photo interpreter must know the basic mechanics of photogrammetry. For this reason, fig. 11, which describes the process of measuring relative differences in elevation of points from vertical air photographs, is included.

85. Cross-sectional shapes. For the purposes of this report, four variations of cross-sectional shape are recognized: undulating, rolling, created, and blocky. Examples of these shapes are shown in fig. 12. It must be recognized, however, that these four forms grade into each other in complex ways, so that a decision as to which type is being exhibited by any given topographic surface may be very difficult. In spite of such possible confusions, analysis of cross-sectional shape is important because each type has certain general implications as to underlying structure, parent materials, erosional or depositional history, and climatic regime. In the descriptions of the specific landscapes in Parts V and VI of this report, these terms are used only to set the stage; the individual variations and characteristics of each landscape are modified by suitable and more classical descriptive terms.

86. Although the infinite variation of cross-sectional shapes makes

precise definition difficult, the following generalizations have been employed in this report.

- a. Undulating shapes are composed of smooth sigmoidal curves of very small amplitude, as illustrated in fig. 12, examples a and b.
- b. Rolling shapes are composed of smooth sigmoidal curves of relatively small amplitude, as illustrated in fig. 12, examples c and d.
- c. Crested shapes are composed of relatively straight lines meeting at an apex, as illustrated in fig. 12, examples e, f, and g. The topographic lows (i.e. the areas between the uplands) need not be V-shaped; for example, those illustrated in fig. 12, example e, are rounded. Crested shapes may occur with any amplitude.
- d. Blocky shapes are composed of relatively straight lines with the tops of the topographic highs flat or nearly so, as illustrated in fig. 12, examples h and i. Such shapes may occur with any amplitude.

87. It should be noted that there is no necessary implication of size in this classification. It is solely a classification of shape, with no specific correlations with any other factor or aspect of the environment. Because the types grade into each other, many instances will be found in which no precise class can be assigned. Furthermore, many landscapes are combinations of two or more types. For example, a region may have the gross configuration of a blocky surface, but still be a region in which the topographic lows are undulating and the topographic highs are rolling.

88. Restrictive use of descriptive terms. In addition to terms describing cross-sectional shape, certain general descriptive terms frequently employed in the literature are used in this report in a somewhat restrictive sense. These are: valley, basin, lowland, plain, plateau, hill, mountain, ridge, and terrace. It should be noted that these terms are by no means mutually exclusive, nor do they by any means include all possible shapes or materials combinations. For example, valleys are an inherent part of plains, hills, mountains, and ridges, and a ridge can obviously be either a mountain or a hill, or even occur in a plain. As used in this report, the terms are defined thus:

- a. Valley. A depression in the surface drained by a surface channel. No implication of scale or shape is intended.
- b. Basin. A depression in the surface not drained externally

by a surface drainage channel. No implication of scale or specific shape is intended. Thus, Death Valley and the small closed depressions common on outwash surfaces are both basins. It should be noted that valleys may (and commonly do) occur within basins, and vice versa.

- c. Lowland. That portion of a valley which has been formed primarily by fluvial depositional processes.
- d. Plain. A surface of less than 500 ft of local relief and formed on essentially horizontal or very gently inclined materials.
- e. Plateau. A surface of more than 500 ft of local relief and formed on essentially horizontal or very gently inclined materials.
- f. Hill. A surface of less than 1000 ft of local relief and formed on (or from) materials having inclined bedding or having no bedding. This term might be used to describe such diverse features as dunes, pyroclastic cones, linear moraines, or surfaces eroded from intrusive igneous rocks.
- g. Mountain. A surface of more than 1000 ft of local relief and formed on (or from) inclined or nonstratified materials.
- h. Ridge. An elongate topographic high. No implication of size is intended.
- i. Terrace. An essentially horizontal surface of relatively low relief bounded on one or more sides by a topographic low, and sometimes on the remaining side or sides by a topographic high.

Local erosion

89. Those minor features of the landscape produced by extremely localized concentrations of erosive energy, whether of air or water, are termed "local erosion" in this report. Two principal types are important to the photo interpreter: water erosion and wind erosion. Features produced by these two forces, as recorded on airphotos, are important aids in interpretation because they are commonly diagnostic of surface soil textures and to a lesser extent of soil profile characteristics and soil moisture conditions. The specific implications of each type are discussed in the following paragraphs.

90. Wind erosion. Evidences of wind erosion are chiefly the following: blowouts, which are normally smoothly rounded and irregularly shaped depressions; sand streaks, which are commonly light-toned, but poorly defined, parallel streaks; and sand blotches, which are irregular, light-toned, and poorly defined patches. Evaluation of such features depends on

such background information as prevailing wind direction and velocity, and on general climatic regime. The latter is important chiefly in that it allows at least crude estimates of the probable soil moisture conditions. Any surface unprotected by vegetation and not continuously moist may be eroded by the wind. Furthermore, both local and regional topographic configurations must be kept in mind when evaluating eolian action, because mountains, hills, or other features may so channel air movements as to multiply erosive power in one locality and minimize it in another.

91. Lacustrine plains, glacial-fluvial plains, alluvial aprons and fans, beaches, plowed fields, gullied slopes, and floodplains are types of surfaces which are especially subject to eolian erosion; such areas commonly exhibit traces of direct erosion, and may contribute substantial amounts of transportable material for removal and deposition downwind. In general, the finer the grain size the greater the distance the material is moved, all other things being equal. As a result, a blowout with evidence (such as a dune or a sand smear) of immediate deposition downwind implies relatively coarse-grained material, whereas a blowout without such evidence implies fine-grained material.

92. Many erosional forms resulting from wind action are, at best, difficult to identify on airphotos, chiefly because of their relatively small scale. In general, only the larger blowouts are readily identifiable. Evidence of deposition is commonly more readily evaluated, because the resulting dunes or sheets are clearly visible as either distinctive shapes or as light-toned streaks or blotches. These are of considerable significance for trafficability purposes. In any given locality wind-deposited materials tend to be of uniform size, resulting in homogeneous soils. This in turn implies that soil trafficability conditions in any one locality will be approximately uniform, provided slope, vegetation, and moisture conditions are similar.

93. Water erosion. Moving water is the major agent active in developing the surface configuration of the earth. Despite its awesome power in extreme forms, such as floods and tidal waves, it is also so delicately responsive to variations in environment that even modest changes in the material being eroded or the climatic regime can profoundly modify the surface expressions produced. As a result, the landscape patterns produced

through the agency of moving water are of great importance to the photo interpreter. However, the interpreter must have at least a basic knowledge of the interrelations between climate, surface materials, surface configuration, and vegetation. This is because the relative importance of the various factors influencing runoff varies depending upon the specific environmental conditions which occur in any given area. Accordingly then, interrelations can be stated only as general principles, which can be employed only with the clear understanding that the validity of each statement is sometimes modified by other conditions. These fundamental principles are:

- a. The amount and intensity of rainfall determine the amount of runoff. A large amount of rainfall of short duration may produce more runoff than the same amount over a longer period of time.
- b. The amount of runoff is dependent upon the amount of moisture in the soil prior to rainfall. A given rainfall on wet soil will produce more runoff than the same rainfall on dry soil, because a certain proportion of the incident water will be stored by the dry soil, whereas the wet soil has much less available storage capacity.
- c. A noncohesive soil is removed more readily by runoff (i.e. eroded more readily) than a cohesive soil.
- d. The greater the permeability of a soil the less the surface runoff.
- e. In general, the greater the density of vegetation the less the runoff for a given quantity of incident water because of wetting of the vegetation and litter.
- f. The steeper the slope the greater the runoff.

94. In general, there are three relatively distinct processes by which moving water erodes material and in so doing modifies the shapes composing a landscape. In this report, these processes are called sheet, rill, and gully erosion. Although there are obviously no naturally fixed lines of demarcation between the various types, in this report they have been arbitrarily separated and described individually in order of the magnitude of their effects, and of the patterns they produce.

- a. Sheet erosion. When water falls upon a gently sloping soil surface in just the right quantity, it may, assuming the characteristics of the soil are appropriate, flow off in a thin, relatively smooth sheet. In this state, it may remove soil particles from topographically high surfaces in an

amazingly regular manner, and deposit them at lower elevations (reference 27, page 588; reference 28, page 583). This process is known as sheet erosion.

- (1) Effects of sheet erosion. As a result of sheet erosion a smooth gradation of soil textures, from relatively coarse-grained materials on topographic highs to relatively fine-grained materials on topographic lows, usually occurs. This implies that, assuming the soils are wet (i.e. near field capacity), the soil strengths will usually be stronger on the high and weaker on the low topographic positions. Also, a similar smooth gradation of organic content of the soils, from low on the topographic highs to high on the topographic lows, may occur. All other things being equal, a high organic content in a soil implies a lower CI and usually a lower RI. Thus, where sheet erosion has occurred, low-lying soils will in general be expected to be less trafficable than upland soils, because they tend to be wetter and remain wet for longer periods. Certain combinations of soil conditions are more conducive to this form of erosion than others. In general, these are: a thin layer of loose (i.e. friable and permeable) soil underlain by a compact subsoil of low permeability; sandy and silty soils; and soils having very low organic contents (reference 27, page 584).
 - (2) Photo evidence of sheet erosion. Evidences of sheet erosion should be sought on any gently sloping surface, especially if the soil is unprotected by vegetation. Commonly, but not invariably, a change in soil color, as revealed by gray photo tones, from the top to the bottom of the slopes indicates sheet erosion. However, this criterion should be used with caution, because other factors, such as vegetation changes and the angle of incident light, may produce similar appearances on a photograph.
- b. Rill erosion. If for any reason the water incident upon a sloping soil surface concentrates into streamlets, even very small ones, rill erosion is instituted. These tiny streamlets rapidly erode the slope into a succession of tiny gully-like forms, each of which may be only an inch or so deep. A few of the rills grow larger at the expense of those adjacent until at last only a few large ones are left. At that stage they are normally called gullies, though it should be emphasized that this is only one of several mechanisms of gully formation. In general, rill erosion can occur on virtually any soil during periods of heavy rain. However, if the soil is reasonably thick, an exceedingly heavy downpour is required to produce rills on permeable soils. Intense rill erosion develops on soils of low infiltration capacity. Among the most susceptible soils

are those in which a thin, permeable soil overlies a less pervious subsoil (reference 27, page 585). Homogeneous, deep, silty soils are also exceedingly susceptible. Very commonly rill erosion can be recognized on aerial photographs by a white or light-toned fringe around the area of active gully erosion. This is illustrated in fig. 6 and identified by marginal arrows designated "A."

- c. Gully erosion. As used in this report, gully erosion consists of the incipient or poorly developed channels tributary to the main channels. Gully erosion is the advanced stage of rill erosion which usually follows sheet erosion. These incipient channels, the headmost expression of the entire drainage system, are known by a variety of local names, gully being perhaps the most common. An elaborate system of gullies is illustrated by the locations identified by marginal arrows "B" and "C" in fig. 6. The shape of a gully, in plan, profile, and cross section, is closely related to the materials in which the gully is being formed. It is influenced by the texture, cohesiveness, and permeability of both the surface soil and subsoils. Unfortunately, the significance of gully shape varies to a considerable degree with climate. Therefore, a knowledge of, or photo recognition of the climatic regime is an indispensable requisite for gully analysis. The basic gully shapes, classified according to the gully cross section and gradient, are illustrated in table 5. Although gullies are important indicators of soil characteristics, they should not be used alone to interpret the trafficability properties of soils. This is because gully forms are to some extent controlled by vegetative cover, topography, and land use. For example, the dense root mat of some sod-forming grasses may bind sandy soils so tightly that gullies may be the FV type (see table 5), even though the soils are sandy and well drained throughout.

Vegetation

95. Vegetation is commonly a delicate indicator of environmental conditions, and is therefore often of great value to the photo interpreter. However, it is affected by such a multiplicity of environmental factors that interpretation on the basis of vegetation alone must be made with great caution. The interpreter must have an extensive background knowledge of the region, especially of its climatic regime.

96. In many cases individual plant species are indicators of specific and very narrow ranges of environmental conditions, such as soil type and moisture relations. However, species cannot normally be identified from airphotos except at very large scales, although notable exceptions

occur. For example, a distinctive shape of crown may positively identify a particular species in some places. Inability to identify particular species forces the interpreter to rely on general patterns. These are so numerous, and so widely variable from region to region, that all are not described in this study. However, some notable examples of general patterns are:

- a. The marked tendency of certain plants to concentrate along desert washes, indicating a slightly more persistent soil moisture than in the surrounding uplands.
- b. The concentric zones of vegetation around lakes and ponds, especially in cold-humid regions. For example, a common zonation around lakes in Quebec Province of Canada is, from the water outward, the sedge zone, heath zone, and spruce zone.⁹ This zonation indicates successive reductions in waterlogging of the soil, and is also to a degree a measure of the amount of organic material in the soil. The sedges may actually be floating, the heaths normally rest on peat, and the spruce grows in highly organic silty soils.
- c. In the Lower Mississippi Valley floodplain, a heavily forested area commonly indicates high water table and extreme susceptibility to flooding. This is often an indicator of clayey or silty soils with poor internal drainage and high organic content.
- d. A combination of tall grass or sedges and a reticulate drainage pattern commonly indicates fine-grained, highly organic soils subject to repeated tidal flooding.
- e. In the hardwood forest belt the oaks, such as scarlet oak and scrub oak, that hold their leaves in winter are indicative of dry soils such as sands. Stands of poplar, birch, maple, walnut, and red and white oaks indicate moist, fine-textured soils; and sycamore, cottonwood, and willow indicate wet soils. Large-scale photographs are necessary to identify tree species.
- f. In coastal plain areas, wet soils will generally show dense tree growth of hydrophytic types whereas the dry soils exhibit less dense tree growth.
- g. Muck and peat bogs that are waterlogged can readily be differentiated as a contrast in vegetation with the surrounding forested or cultivated land.

97. In general, the photo interpreter should be alert for any change or modification of vegetation pattern, because this is almost invariably an indication of changing environment that may influence trafficability conditions. Interpretation of the precise meaning of such pattern changes

must rest on an intimate background knowledge of the area. In this light, photo interpretation keys of vegetation types taken at different scales and seasons may assist the interpreter (reference 3, page 556).

Cultural influences

98. The practices of man in adjusting himself to his environment can be important in evaluating trafficability conditions from aerial photographs. Terrace farming, dead furrowing, and gully erosion control usually signify a friable soil on a less pervious subsoil. Windbreaks and strip cropping are man-made methods of controlling wind erosion. The various pits and excavations made by man may be significant to interpretation of parent material types and soil textures if other features are visible that signify methods or needs for processing. Although man-made practices are a part of, or are related to, the natural elements of the environment, the individual study of the cause and effect of such practices may have an important bearing on interpreting trafficability conditions. Cultural practices may also be the most confusing pattern observed on aerial photographs.

Seasonal influences

99. The comparison of any one photograph or photo mosaic with another of the same area taken in different years or at different times of the year may, at first glance, suggest completely different areas. This effect is most pronounced in areas having climatic regimes involving pronounced seasonal changes. Thus, the effect may not be detectable in the humid tropics, and it may be very minor in temperate-zone deserts and even in the so-called boreal forests, where dense stands of relatively unchanging evergreen trees mask the ground. However, in humid-temperate regions, and especially in those under intense cultivation, not only the vegetation and soil moisture patterns may change, but even the outlines of the fields themselves. The following paragraphs discuss seasonal photo variations and effects of scale which are applicable, in general, only to regions having humid-temperate climates.

- a. Summer. Photographs are dominated by dark tones produced by intensely green, growing crops and heavily foliated trees. Soil moisture content is normally relatively low, so that bare soil tends to photograph light gray. Field patterns are somewhat subdued because fields are green.

- b. Autumn. Field patterns are relatively distinct because of various stages of crop development and harvesting. Variations in tone resulting from variations in soil moisture content are subdued. (See fig. 13, 13 Oct 1953.)
- c. Winter. Photos are drab and dull, with some field patterns indistinct. Mottling due to variations in soil moisture is practically nonexistent, and bare ground tends to photograph dark because soil moisture content is uniformly high. Low angle of incident light makes sharp shadow patterns in wooded areas, producing a distinctive form of flecked texture. (See fig. 13, 17 Dec 1952.)
- d. Spring. Field patterns are sharp and distinct due to differences in the state of tillage and crop development. Mottled textures due to differences in soil moisture content are very distinct; high topographic positions, even those only a few feet or inches above the adjacent low positions, tend to photograph light, while low topographic positions photograph dark, because of large local variations in soil moisture. This is the best season for obtaining soil trafficability pictures because all differences in the relations between soil types and soil moisture are emphasized. (See fig. 13, 20 May 1954.)

100. At large scales the minor features, such as gullies, rills, and vegetation textures and patterns, become more obvious. The gullies (fields 3 and 4, fig. 6) are usually far more pronounced during the winter than during the summer because the low winter sun casts denser shadows, and the dormant, leafless vegetation does not mask the surface. Field 2, figs. 6 and 7, shows a combination of mottled and flecked textures during both winter and summer, implying not only pasture type of vegetation but also very probably a good deal of surface roughness. Recently cultivated fields (field 4, fig. 7) show very light photo tones and imply good internal drainage of the soils in the area.

101. Seasonal variations can be observed at large scales as well as small scales, but the features by which the seasonal changes are identified are quite different. For example, the subdued field patterns observed in winter photographs at small scales are produced in part by the lack of foliage on the trees, but the individual trees cannot be seen (see fig. 13). On the other hand, the leaflessness is clearly apparent on individual trees in photos taken at large scales (see fig. 6), and the resultant flecked pattern is distinctive. At large scale, the difference in terrain appearance between winter and summer is illustrated by a comparison of figs. 6 and 7.

Elements Derived by Deduction

102. In general, the elements just discussed are those which permit a direct interpretation of the patterns or textures on an airphoto. There are, however, certain attributes of the landscape which do not permit this direct interpretation, but which are nevertheless important for trafficability purposes. In fact, the photo and terrain elements just discussed are valuable chiefly because they provide the data from which deductions can be made of the nature of the factors directly affecting trafficability. The aspects of terrain important to trafficability are those that permit identification of soil characteristics. To deduce such factors, an intervening step between the directly interpretable patterns and textures (the photo and terrain elements) and those factors identified purely by deduction (soil characteristics) must be established. This step consists of the identification of parent materials. Accordingly, the following discussion of factors derived by deduction is divided into two sections; the first establishes a classification of parent materials, and the second discusses soil properties pertinent to trafficability.

Parent materials

103. The materials from which the soils of a given landscape were derived are the parent materials of that landscape (tables 6 and 7). These materials are of fundamental importance because they control to a considerable degree, or at least strongly influence, the characteristics of the soil. Knowledge of the nature of the parent materials, coupled with subsidiary information on climatic regime, structure of the crust, erosive history, and cultural history, makes it possible in many cases to estimate the resulting soil properties with considerable precision. Thus, every effort should be made to establish the nature of the parent materials of a region before an attempt is made to interpret the photos. Failing this, parent materials must be established by deduction by applying the implications of topographic shape, drainage properties, etc. Table 8 is a compilation of some of the more common relations. However, the table should be used with the clear understanding that it does not include all possible configurations and implications.

104. Two separate classification systems have been used for parent

materials, one each for consolidated (i.e. rocks) and unconsolidated materials. This was done because different combinations of conditions or attributes are important in each of these two types of materials; therefore, a single internally consistent classification covering both is difficult, if not impossible, to establish.

105. The two classification systems are not strictly comparable. For example, rock (i.e. consolidated materials) is subdivided on the basis of a broad interpretation of mode of origin (sedimentary, igneous, and metamorphic), while the subdivision of unconsolidated materials is based on a much narrower interpretation of mode of origin. For example, with the possible exception of unconsolidated volcanic materials, all the primary categories in unconsolidated materials are essentially sedimentary. As a result of these distinctions between the degree of significance of correlative processes with respect to rocks and unconsolidated materials, the parent material classification has been divided as indicated in tables 6 and 7. This dual classification was adopted for the following reasons:

- a. In general, the landscapes derived primarily from rock (i.e. limestone, rhyolite, etc.) were formed for the most part by erosional processes of one kind or another, with only relatively small portions having been formed by depositional processes.
- b. On the other hand, in the case of unconsolidated materials, the landscapes resulting from the initial depositional processes are largely retained, or are only slightly modified by erosional processes. Thus the mode of deposition is of considerable aid in deducing the nature of the material.

106. Consolidated materials. As stated earlier, the classification of these materials (see table 7) is based primarily on mode of origin. The second step in the classification scheme is based on the presence or absence of stratification. In addition to the effects produced by stratification alone, the attitude of the beds, if any, is generally of considerable importance. For example, structural folding or faulting which results in inclined or otherwise distorted beds may in some instances influence soil formation by altering internal drainage, the development of surface drainage patterns, the proportions of parent materials exposed to weathering, and so on. The third step in classification is based on a combination of mineralogy and grain size. Mineralogy is important because differences

in chemical composition and crystallographic organization result in marked differences in resistance to weathering and in the resulting weathering products. This factor is thus a major control in the formation of soils.

107. Unconsolidated materials. The classification of these materials (see table 6) is based primarily on mode of deposition because this factor to some extent influences both the mineralogy and such physical properties as the degree and type of stratification. Thus, lakebed deposits (lacustrine materials) would be expected to be stratified while streambed deposits (fluvial materials) would be expected to be more irregularly stratified. Again, deposition within a closed arid basin almost invariably results in the formation of evaporites, whereas these mineralogically peculiar materials are almost always absent from valleys. The second step in this classification is based on grain size of the parent material because this property to some extent controls the grain size of the soils that develop on them. The grain size of the soil, to some extent, affects the strength of that soil. It may also influence the rate of weathering, and hence, the development of the soil profile.

Soil properties pertinent to trafficability

108. Knowledge of the nature of the parent material composing a landscape is important primarily because it provides one of the fundamental items of information necessary in estimating soil properties. As noted in Part II, the process of estimating soil properties begins with the fitting of the soil into a classification system, followed by estimation of the soil's CI and RI. Because the soil classification system used for trafficability purposes (the USCS) is based primarily on grain size, primary importance must be attached to those soil-forming factors that contribute to the grain-size distribution actually found in natural soils. However, an important secondary criterion for classification (and of primary importance in estimating soil strength) is the plasticity of the soil; accordingly, those processes which control plasticity must also receive close attention. Thus, the following discussion of soil-forming factors and processes is intended to assist in the estimation primarily of grain size and plasticity, and only secondarily in the estimation of mineralogical composition, organic content, soil structure, and soil moisture. Rather than attempt a

description of each soil type and the possible ways in which it could have been formed (a task made impossible by the complexity of the soil-forming processes), the soils are discussed generally in terms of fundamental soil properties, and of the processes and conditions which most obviously affect those properties. The implications of each soil property as it is related to soil strength are also examined.

109. "Grain size" refers to the sizes of the individual particles composing a soil. While the particles themselves rarely, if ever, change in size within a short period of time, the arrangement of particles within a specific soil profile may change markedly. This is because soils are the result of a complex of simultaneously operating conditions and processes, any one of which may change abruptly; such a change in environment may induce significant modifications in the concentrations of particles in certain soil horizons. A notable example of this is the formation of a relatively impermeable, clayey "plow sole" within a few years of the inception of agriculture. Apparently the disturbance incumbent upon plowing makes it possible for clay particles to move downward to a point just below the plow base, thus decreasing the mean grain size in that horizon, and increasing it slightly in the horizon above. Thus the grain size is a function of the parent materials, the erosional and depositional history, the climatic and biotic environment, and what might be called the "cultural environment." Each facet of the soil's history and present situation must be understood before an attempt can be made to estimate its texture. Indeed, this is also true for all other soil properties as well.

110. Soil texture is the result of chemical and mechanical weathering processes acting upon parent material in place during long periods of time. The parent material may be consolidated or unconsolidated, and may be any one of a virtually infinite number of possible mineral combinations. In general, the texture of a soil is most closely related to both the texture and chemical composition (i.e. the mineralogy) of the parent material. For example, dune sand, which is normally composed primarily of the very stable mineral quartz, will remain essentially unchanged for long periods of time, and the soils which eventually form on it will remain sandy. On the other hand, limestone, the principal component of which is the relatively unstable mineral calcite, weathers relatively rapidly into a clayey

soil regardless of the original texture of the limestone. Thus, all other things being equal, a soil formed on a parent material consisting primarily of stable minerals tends to closely reflect the texture of the parent material, while soils formed on parent materials composed of unstable materials tend to be much finer grained than the original material.

- a. Effects of parent material. Since most parent materials contain at least a substantial proportion of unstable minerals, the majority of naturally occurring soils fall into the fine-grained soil groups of both the USDA and the USCS, although notable exceptions to this generalization occur, particularly in areas of desert and arctic climatic regimes. These climates produce such exceptions chiefly because chemical weathering, the process which ordinarily produces most clay- and silt-size particles, is inhibited by cold, or by the lack of water or vegetation, or by all three.
- b. Effects of topography. Topographic position may also strongly affect the grain size of a soil. However, the possible variations in the effects of topographic positions are so many and so large that all generalizations should be viewed with caution. In general, soils on high topographic positions tend to be more coarse grained than soils on low positions. This is because both wind and water tend to selectively remove the smaller particles and redeposit them in the topographic lows. Thus, an originally homogeneous soil tends to become impoverished of fines on the topographic highs, and enriched by fines on the topographic lows.
- c. Effect of deposition. Wind-deposited soils are invariably uniformly graded silt or fine to medium sand. On the other hand, water- or ice-deposited parent materials produce soil textures ranging from clay to boulders, depending primarily on the velocity of the water at the point of deposition.
- d. Trafficability implications.
 - (1) Fine-grained soil. Fine-grained soils are composed predominantly of silt- and clay-size particles, although sand mixtures are not uncommon. In general, the characteristics of silt soil are distinct from those of all other textural types. When they are wet they are generally characterized by low CI and RI values, making them the poorest of all soils from the standpoint of trafficability. Clay soils generally have higher CI and RI values than the silts, but they have disadvantages peculiar to themselves. Clays, especially those of high plasticity, tend to become sticky and/or slippery when wet, thus impeding vehicular movement.
 - (2) Coarse-grained soil. Coarse-grained soils (i.e. those

in which the predominant particles are in the sand size range) generally have relatively high CI and RI values, and therefore cause little difficulty to vehicular movement. However, this generalization must be strongly qualified if the sands are composed of loosely packed, clean, dry sand grains. In such soils wheeled vehicles tend to lose traction, especially on slopes, with resulting loss of mobility. Even a small increase in water content will materially improve the trafficability characteristics of such soils.

- (3) Sand with fines, poorly drained. Sandy soils containing more than about 7% silt- or clay-size particles have characteristics somewhat similar to those of the fine-grained group. Wheeled or tracked vehicles with high contact pressures are commonly immobilized in wet soils of this type (particularly if the fine fraction is silt), chiefly because such soils have relatively high CI values but, in some instances, very low RI values. Such soils are normally critical from the trafficability standpoint when the water table is within 2 ft of the surface, because capillarity tends to keep the soil of the upper 2 ft at or near saturation.

111. Soil moisture. Water exists within the soil in four different ways (reference 27, page 902):

- a. Gravitational water is free water that percolates downward through subsoil and drains away or runs off during or after rains.
- b. Capillary water is the water that remains after gravitational water is removed; it is held by capillary attraction, and it moves in the direction of greatest capillary tension; it is removed by evapotranspiration.
- c. Hydroscopic water is the water that remains after capillary water is removed; it exists as thin films on soil grains and colloids; it can be removed only by evaporation.
- d. Combined or "interplanar" water is the water that is held in chemical combinations and will not evaporate; it can be driven off only by heating to temperatures well above those reached naturally.

112. It is evident that there can be no sharp lines of demarcation between the various types of moisture. From the standpoint of soil trafficability, gravitational water is the most important. In general, fine-grained soils containing water in this form are normally nontrafficable, though notable exceptions to this generalization occur.

113. Soils in which all interstices are filled with water are said

to be saturated. When a soil in this state is drained of all water free to move by gravitational forces, the soil is said to be at field capacity. A soil containing water in excess of field capacity (i.e. a soil in which some gravitational water is present), which for some reason cannot escape, is waterlogged.

114. From the standpoint of trafficability, moisture contents at or above field capacity are the most important, because for most fine-grained soils or coarse-grained soils with fines this range of moisture contents is well above the plastic limit of the soil. In general, when the moisture content of medium-textured soils is at or above the plastic limit, the soil becomes untrafficable.

115. Soil moisture is rarely either uniformly distributed or in a state of static equilibrium. Great fluctuations of moisture content occur in both time and space. Normally, the greatest variations occur near the surface of the soil because of the marked and sometimes violent atmospheric fluctuations, but substantial changes can also occur at lower depths as a result of water-table variations or other causes. The normally close relation between soil moisture and atmospheric conditions has led to studies that have established empirical relations between climatic factors and rates of accretion and depletion of soil moisture.^{21,24} However, the nature of the soil itself is a factor in this process. Accordingly, the WES in cooperation with the U. S. Forest Service has studied methods of incorporating both climatic and soil data into a system for predicting soil moisture. The Air Force Cambridge Research Center has also investigated soil moisture prediction methods¹⁹ using a somewhat different approach than that used by WES.

116. The WES studies have shown that in regions of the northern hemisphere having humid-temperate climatic regimes, a definite seasonal variation in soil moisture occurs, with high soil moisture values in the winter (November to March), low values in summer (June to August), and intermediate values for spring and autumn (April, May, September, and October). The studies also indicated that soil moisture reached a maximum at or above field capacity in midwinter and remained fairly constant until the beginning of spring growth. (A record of daily soil moisture for a specific site located in a humid climate is shown in fig. 14.) It was also found

that accretion (i.e. soil wetting) within the surface foot of soil was dependent upon available storage (i.e. pore space unoccupied by water) as well as on the amount of precipitation. As a result of these studies, a system for predicting accretion and depletion (i.e. soil drying) rates has been developed for all seasons. These relations have been applied to the prediction of actual soil moisture content on a year-round basis with moderate success. The method is not successful in areas influenced by groundwater, or in regions where the ground is seasonally frozen, because both of these factors inhibit or prevent the normal processes of accretion and depletion. Since the soil strength is generally lowest at maximum moisture content, the winter (or wet season) soil moisture maximum permits an estimate of the worst trafficability conditions that would be encountered.

117. Consideration of the above discussion indicates that soil moisture relations must be established before an adequate estimate of soil strength (and thus of trafficability conditions) can be made. In order to properly evaluate soil moisture relations in any given area, it is evident that a thorough knowledge of the climatic regime is required. If possible, knowledge of general climatic conditions should be modified by detailed information on weather fluctuations. Specifically, rainfall records should be studied before any attempt is made to judge soil moisture conditions.

118. Soil moisture data included in this report were collected on visits to each of the test sites. An attempt was made to visit each site during the wet and dry seasons of the year, but in some instances sites were visited only during the wet season. At some sites the visit coincided with an abnormally long dry spell, even though the visit was made during the wet season. Consequently, in some instances the wet season moisture contents were lower than the dry season moisture contents.

119. Soil structure. In this context, soil structure is the aggregation of soil particles into groups or clusters separated by planes or zones of weakness. Four primary types are recognized: (a) spheroidal, (b) platy, (c) prismatic, and (d) blocky (reference 29, page 225). The structure of the surface soil is important from the standpoint of trafficability in at least two ways: first, the structure may influence the ability of the soil to hold water (i.e. its permeability); second, it may directly contribute to or subtract from the soil strength.

- a. Spheroidal. The spheroidal structure commonly occurs in regions where the dominant vegetation under which the soil developed was grass. This is, therefore, a common structure in prairie regions. The spheroidal structure tends to increase the effective permeability of the soil, so that gravitational water tends to be lost somewhat more rapidly than would otherwise be the case. Further, the relatively free circulation of air allowed by the soil structure is conducive to rapid drying because it allows large volumes of unsaturated air to be brought into contact with the soil water, thus hastening evaporation more so than is the case for other soil structures.
- b. Platy. Platy structures commonly reduce internal drainage because the surfaces of weakness are normally horizontal. These surfaces tend to concentrate fines to such an extent that the effective vertical permeability of the soil is reduced.
- c. Prismlike. The aggregation of soil particles in prism structures forms larger soil clusters than spheroidal structures and they have distinctive vertical planes of weakness. The aggregates look like columns with flat sides. The vertical planes of weakness improve vertical drainage but not to the extent of that evidenced in spheroidal structures.
- d. Blocky. Blocky structure aggregates are bound by rounded or flat surfaces. The aggregate cluster may not have an elongated dimension. The number of planes of weakness produce a better vertical drainage than that in prism structures.

There is no known correlation between soil structure and soil texture. Instead, structure appears to be related chiefly to the weathering history and the biotic environment, though the relations are so poorly understood that no general statements are possible. As a result, soil structure is very difficult to evaluate for trafficability purposes from aerial photographs. As a general rule, attempts to infer soil structure are valid only when the interpreter has long and intimate experience with the area being examined. Even in such instances the background information should include, in addition to the usual material, data on the biotic and cultural history. The latter is especially important, because land-use methods commonly produce artificial structures. For example, deep plowing of dense and clayey soils tends to produce a blocky or prismatic structure, whereas harrowing produces a surface layer of spheroidal structure.

120. Soil density. Soil density refers to the unit weight of the

soil and is normally measured in pounds per cubic foot. In general, the density of a soil is a function of its texture, structure, void ratio, and mineralogy. The number of independent variables contributing to soil density makes it difficult to draw valid generalizations for this property. However, certain statements can be made, even though each must be understood to be prefaced by the qualifying phrase, "All other things being equal." These are:

- a. Soils having very little range in grain size (i.e. all soil particles approximately equal in size) have low densities, while those in which the grain size is well graded from fine to coarse have high densities.
- b. Soils having a high proportion of organic material generally have low densities.
- c. Soils having high void ratios have low densities. This statement is in part a corollary of a above, because soils comprised of grains of approximately equal size normally have a higher void ratio than well-graded soils.
- d. Soils having spheroidal structure generally have higher densities than those having prismoidal or blocky structure.

121. There is normally a direct though not strictly proportional relation between soil density and soil strength. Soils having low densities commonly (but not invariably) are typified by low values of CI and are therefore poor from a trafficability standpoint. In addition to their low shear strength (as measured by the cone penetrometer), such soils are also quite compressible, particularly if organic matter is present. This is because low soil density is very generally a result of a high void ratio. Under pressure the soil structure tends to collapse into a more compact and therefore denser arrangement of its component particles. The combination of collapse and shear failure tends to produce ruts under vehicles even when contact pressures are relatively low. When free water is present it tends to accumulate in the ruts, where successive passes mix it with the soil, thus still further reducing the soil's ability to support vehicular movement.

122. The shear strength of low-density soils, as measured by the cone penetrometer, is largely independent of depth. However, an otherwise similar soil of high density exhibits a steadily increasing shear strength with depth. This is commonly of significance in considering the movement

of high-contact-pressure vehicles; even though the top few inches of a given soil may be below the critical strength, the strength in the critical layer may increase with depth rapidly enough to permit movement.

123. The number of independent variables that contribute to soil density, and the range of environmental conditions that can affect one or more of the variables make it very difficult to interpret soil densities from aerial photographs. For example, raindrops falling on the bare soil of a newly plowed field may disperse the soil aggregate, increase compaction, and thus increase the density of the surface layer. Although commonly very thin, such a high-density layer may so alter the air circulation and moisture relations within the entire soil mass that its trafficability characteristics are materially affected. Another common surface-layer effect is that produced by desiccation, a common phenomenon in arid and semi-arid regions. This phenomenon is especially effective in producing a dense surface layer in places where capillarity brings salt-laden water to the surface, where it evaporates. The salt may then partially seal the interstices, forming a dense, compact, and highly trafficable surface in materials which would otherwise have a very poor trafficability characteristic.

124. It is evident that the photo interpreter must be conversant with the soil-forming processes, including the mode of deposition, when attempting to deduce soil densities from aerial photographs.

125. Soil drainage. External drainage (i.e. runoff) is a function not only of the ground slope and the soil texture, but many other factors as well, including soil structure, vegetation, and certain attributes of weather of which the most important are the duration and intensity of precipitation. External drainage normally adjusts very rapidly and delicately to changes in environment. This factor makes drainage analysis on either a regional or local basis a very fruitful source of information for the photo interpreter.

- a. Regional drainage. Commonly the regional drainage pattern is indicative of the topographic and vegetative expressions as well as the soil conditions to be expected in the area. This is because the regional drainage tends to adjust to such conditions as underlying rock structure, rock type, joint patterns, topographic position, etc., thus providing the interpreter with a fund of basic information from which to deduce more detailed information.

- b. Local drainage. Local external drainage, especially gullies and incipient streams (i.e. drainageways of low order), commonly is adjusted to both soil type and soil profile. Thus, an examination of incipient drainageways may reveal much detailed information on soil texture, permeability, and stratification.
- c. Internal drainage. The internal drainage of the soil depends not only upon the permeability of the soil itself, but also upon its topographic position, the nature of the underlying material, and in some instances the depth to the water table.
 - (1) Permeability. In the sense used in this report, permeability is a measure of the ability of a given soil horizon, or of the entire soil mass, to transmit water. The water may migrate through either or both the pores of the soil or the planes of weakness defining the aggregations composing the soil structure. The ability of the soil to transmit water internally is primarily a function of the size of the pores, the void ratio, and the structure; but the kind and amount of surface area of the soil grains are also influential.
 - (a) Pore size is the most important factor affecting permeability. All other things being equal, the larger the pores the more rapid the internal drainage of the soil. For example, soils composed of equal-size, coarse-grained particles (e.g. clean, coarse sands) retain very little water internally because the large pores make it impossible for capillary forces to hold water in them, and the small surface area available (the total surface area of the particles in a soil is inversely proportional to particle size) retains but small amounts of hygroscopic water.
 - (b) Void ratio has an important bearing on the amount of moisture retained in a soil and is in general inversely proportional to particle size. The range in void ratio as a function of particle size is striking; it varies from about 0.3 in some sands to about 0.7 in some clays (reference 25, page 903). Clays therefore almost invariably have high moisture-holding capabilities because the forces holding water in the small pores and in contact with the grains are stronger than the gravitational forces, and the large void ratio provides a large volume of space for water storage. Accordingly, clay soils have poor internal drainage. Other factors also contribute to the void ratio. For example, the shape of the particles, and their packing arrangements are

important. In general, a high organic content implies a relatively high void ratio.

- (c) Soil structure is commonly an important factor in internal soil drainage. As indicated in paragraph 119, spheroidal, blocky, and prismoidal structures contribute to rapid drainage of the soil, whereas platy structures inhibit drainage.
- (2) Topographic position and aspect. Topographic position also contributes indirectly to soil moisture variations. Sloping surfaces and topographic high positions provide greater potentials for surface drainage or runoff. Also, aspect or the direction which a topographic high faces influences soil moisture. For example, in the northern hemisphere (especially north of the Tropic of Cancer) evapotranspiration losses tend to be greatest on the south-facing slopes, somewhat less on slopes facing east and west, and least on slopes facing north. Because of the removal of soil moisture and the commensurate increase in soil strength, this means that, all other things being equal, south-facing slopes will be the most trafficable and north slopes the least. In the southern hemisphere the situation is reversed.
- (3) Underlying materials. Few soils are entirely homogeneous; most have several horizons or layers of markedly different permeabilities. This stratification has an important bearing on internal drainage because the drainage of the entire soil mass may be controlled to a considerable degree by the least permeable layer. When this layer is at the surface, the underlying soil mass may remain abnormally dry because the surface layer inhibits infiltration to such an extent that incident water runs off as external drainage. On the other hand, if the least permeable layer is in the subsoil, it may trap water percolating downward until the overlying soil becomes saturated. This condition is, in effect, a "perched" or temporary water table. When such a condition exists, a soil that would otherwise be expected to drain readily may remain abnormally wet for long periods. Further, if the perched water table reaches the surface, then additional incident water can only be removed as surface runoff.

The nature of external drainage can be interpreted directly from aerial photos, but it is evident that internal drainage conditions can only be inferred from other evidence. In general, the technique is to search for anomalies. For example, if background information for a given area suggested that the soils should be highly permeable and therefore well drained, but actual examination of an area

revealed evidence of waterlogged soils (such as a variation in tone, or a change in vegetation), the interpreter might well suspect the presence of an impermeable subsurface layer.

126. Soil stratification. During the normal process of soil formation, most soils develop some stratification. The component beds or layers are of extremely variable thicknesses, depending on the relations between such factors as climatic region, nature of the parent material, topographic position, etc. Although soil scientists have subdivided the soils in many ways, only two major soil layers are significant for trafficability purposes. The surface layer, characterized in general as a zone of leaching and mechanical removal of fines, is called the A-horizon in this report. The subsurface layer, characterized in general as a zone of deposition of both leached materials and fines from the A-horizon, is called the B-horizon. Below the B-horizon lies the relatively or entirely undisturbed parent material. The relation between the relative permeabilities, plasticity, grain sizes, and other factors in the various layers is often of considerable importance in estimating trafficability characteristics. For many soils the critical layer for trafficability (i.e. the layer between the 6- and 12-in. depths) occurs in the B-horizon.

Factors indirectly affecting soil characteristics

127. Topographic position. Many of the implications of topographic position with respect to soils have been discussed in preceding paragraphs. In general, it will be noted that topographic position is important chiefly because it controls to some extent the soil-forming processes. Although the possible variations in the effects of topographic position are so many and so large that all generalizations should be accepted with caution, it is still possible to draw a set of broad generalizations relative to its effect. However, it should be kept firmly in mind that every region tends to have its own array of special conditions which modify the basic generalizations; therefore, the interpreter must obtain background knowledge to determine the possible effects of topographic position in any given region.

128. In the United States the following generalizations commonly, but by no means invariably, can be made. The soils on high topographic positions are generally more loose and friable than those found at low

topographic positions. They also tend to contain less clay and/or humus (i.e. organic material) than low-lying soils. Soils on high topographic positions generally hold moisture for shorter periods because of the greater opportunity for both external and internal drainage. Soils in low topographic positions tend to be darker in color as a result of higher organic content than soils on high topographic positions. In general, soils in low topographic positions are wetter than soils on adjacent high topographic positions.

129. Vegetation. Plant cover in temperate climates rarely affects soil strength directly, but it does affect it indirectly in several ways. It removes soil moisture through transpiration, and thus assists in drying the soil. Because water content is so critical a factor in soil strength, the fact that vegetation reduces soil moisture is of considerable importance. Unfortunately no data are available on the magnitude of this effect, and in fact there is much evidence to indicate that in certain circumstances the effect may actually be reversed (i.e. vegetation results in an increase in soil moisture). The Corps of Engineers in cooperation with the U. S. Forest Service has conducted preliminary studies that indicate that soil moisture depletion within the surface foot is not notably different under different kinds of vegetation but is decidedly different when an area is bare of vegetation. The evaporation rate in the surface to 6-in. layer of bare soil equals and, in some cases, exceeds the evapotranspiration from that layer on vegetated areas. In any event, so little is known of the precise balance of such effects that the photo interpreter should proceed with great caution in estimating soil moisture from vegetation data.

130. Some plants develop dense roots within the top few inches of the soil. This is especially true of sod-forming grasses, although other vegetation types also exhibit this property. The longleaf and slash pine of the southeastern United States produce root mats of this type. These mats act as very rude and temporary pavements to the extent that otherwise untrafficable soils become trafficable, at least until the root mat is destroyed.

PART IV: CLASSIFICATION AND DESCRIPTION PROCEDURES FOR REPRESENTATIVE LANDSCAPES, AND AIRPHOTO INTERPRETATION AIDS

Classification of Representative Landscapes

131. The classification of representative landscapes employed in this report is not entirely rigorous. It is in effect a compromise between the classical systems of describing landscapes and a system designed for the specific purposes of trafficability analyses. The compromise was believed necessary because a rigorous system based on trafficability considerations would introduce unfamiliar terminology in addition to an unfamiliar arrangement and association of landscapes. Therefore, only enough of the trafficability considerations have been introduced to clearly indicate the relations involved.

132. As an example, landscapes formed in unconsolidated materials are described by familiar names (i.e. eolian, glacial, etc.) to permit the use of accepted terminology, but the primary reason for grouping them in the manner used in this report was the degree and perfection of the stratification of the parent materials. This factor is important in trafficability analysis because it influences soil formation, and is therefore a significant component of the information needed to deduce soil trafficability information. Where direct evidence of the degree and perfection of stratification is available, knowledge of the mode of origin is unimportant. For example, from the point of view of the trafficability analyst, it is immaterial whether a clean sand was deposited by a littoral current or a stream.

133. The classification of landscapes as employed in this report is given in tables 9 and 10. The term landscape is used rather than landform chiefly because some, if not all, of the detailed descriptions actually involve more than one landform, if the latter term is used rigorously. For example, a drumlin is a landform, because the entire feature exhibits similar characteristics and was formed in the same way. However, drumlins commonly occur on surfaces having totally different characteristics and formed in an entirely different way than the drumlins. For trafficability purposes, the entire region including both drumlins and interdrumlin areas is

significant. This complex of conditions is called a landscape in this report. Upon examination, virtually every conceivable region is composed of a complex of landforms. For this reason the term landscape has been used to describe a terrain type, while the term landform is used to describe the individual components of the landscape.

Aids in Airphoto Interpretation

134. The interpretation of airphotos requires that all components of the landscape be studied simultaneously, and that the mutual effects and implications be evaluated. Thus, a given drainage type may imply a certain spectrum of structural and parent materials correlations, while the shape of the upland cross sections may imply a somewhat different spectrum, and so on. Only when all existing evidence points to a specific set of conditions can the interpreter be confident of his evaluations.

135. Because it is difficult to keep all possible interrelations in mind when examining airphotos, a table of generalized correlations between important landscape factors is usually of much assistance. Table 8 presents a series of very generalized correlations between regional drainage, topography, local erosion, and parent materials, supplemented with one or several examples of landscapes which exhibit these properties. This table should be used only as a guide, and never as a key. It should be used in conjunction with the descriptions and illustrations in Parts V and VI.

136. It is emphasized that each relation between the elements composing landscapes, as presented in table 8, has many variations as a result of minor (or in some cases major) variations in the history of the soil's development, in local environments, and so on. The table must therefore be used with caution and in the full expectation that few specific landscapes will precisely match the correlations as given.

137. The items listed under the heading "Representative Landscape" in table 8 are followed by a number which refers to the page in Part V or VI where the specific landscape is described in detail. This table, then, serves as an index for locating detailed descriptions of specific United States landscape types.

138. Appendix C consists of nine maps showing the worldwide

locations of major types of generalized landform-parent materials. It is emphasized that these maps are greatly generalized. They should not be used to determine the specific landscape or landform type in any given area. The symbols indicate only that the type may occur in the region; however, other landscape or landform types may occur with equal or even greater frequency.

Procedure for Describing Representative Landscapes

139. In the descriptions of representative landscapes given in Parts V and VI, the order in which the elements are described is roughly that in which the interpreter examines them. Thus, the landscape elements, which are essentially those features of the landscape which result in visible patterns (drainage, topography, erosion, vegetation, and cultural practices), are described first. The features of this group can be more or less directly identified. Following these are the interpretive elements (parent materials and soil profile), which are in general attributes of the landscape that must be deduced from background information and the landscape elements. The interpretive elements are in turn followed by the trafficability and cross-country movement characteristics of the landscape, both as directly measured and as deduced from the airphoto interpretation. The soil data summarized in the discussions of trafficability and cross-country movement characteristics are given in detail in Appendix B. The vehicle categories mentioned are those listed previously in paragraph 27.

PART V: LANDSCAPES IN UNCONSOLIDATED MATERIALS*

140. These landscapes are in general those composed of materials that are unconsolidated. Most, but by no means all, of them owe their present configuration chiefly to depositional processes. Classification criteria are, first, the mode of deposition of the materials composing the component landforms; and second, the topographic configuration (i.e. the shapes of the landforms, and the ways in which they are arranged with respect to each other within the landscape).

141. Although the configurations upon which the categories in this group of landscapes have been based are chiefly the result of depositional processes, almost all have been modified to a greater or lesser degree by erosional processes. For example, in the case of loess surfaces, the existing configuration is one almost entirely resulting from erosional processes; whereas in the case of natural levees, the configuration is almost entirely depositional.

142. In the paragraphs that follow, each landscape is described in terms of landscape elements and interpretive elements. Landscape elements are discussed under the headings of regional drainage, topography, local erosion, natural vegetation, land use, and construction practices. Interpretive elements are discussed under the headings of parent material, soil profile characteristics, and trafficability and cross-country movement characteristics.

Landscapes in Eolian Materials

143. Eolian landscapes are those formed in unconsolidated materials deposited from the atmosphere. However, volcanic materials, such as ash, are specifically omitted from consideration as sources of eolian landscapes because of the peculiar nature of their origin.

Dune fields

144. Major areas of sand dunes occur on every continent, and in virtually every climatic region (see fig. C1, Appendix C). Although the

* In this report, unconsolidated materials are those which can be broken or deformed by the fingers.

largest areas are associated with deserts, extensive dune belts are also found along many coastlines, on the shores of large lakes, and in some instances even along large streams. The most notable dune areas in the United States are in California, Arizona, New Mexico, Washington, and Nebraska. Dunes are exceedingly variable in size, ranging from a few feet to as much as 600 ft in height, and in area from a few hundred square feet (usually isolated barchans) to huge dune fields covering hundreds of square miles.

145. Regional drainage. Surface drainage within the dunes is generally absent. The complete absence of scour channels is a primary recognition feature of all types of dunes, whether active or fixed. Note that in figs. 15, 16, and 17 there are no drainage channels within the dunes, although such channels do exist adjacent to the dune areas. Dunes, being independent of the surface on which they rest, commonly cut across the regional drainage of the predune surface.

146. Topography. Dunes occur in a wide variety of types, with a corresponding variety of surface configuration. The most common types are:

- a. Isolated barchans, in which each dune occurs independently of all others; the cross-sectional shape is asymmetrical and crested.
- b. Transverse dunes, which occur as series of ridges at right angles to the direction of the prevailing wind, as illustrated in fig. 16. The cross-sectional shape is generally asymmetric and crested, with some areas rolling.
- c. Longitudinal dunes, which occur as a series of ridges parallel to the direction of the prevailing winds. The cross-sectional shape is generally rolling, but not infrequently small, sinuous, subsidiary ridges form on the summits of the primary dunes; in such instances, the cross-sectional shape is crested.
- d. Star dunes, which are normally very large peaks from which four or more ridges radiate. The cross-sectional shapes may include combinations of rolling and crested.
- e. Complex dunes, in which dunes of indeterminate or gradational forms occur in such proximity that the forms touch or interpenetrate. The area outlined in fig. 16 illustrates dunes of this type, with the dark, vegetated area being chiefly fixed longitudinal dunes, and the light-toned, almost vegetation-free areas being composed of complexly associated but modified barchan and transverse dune types.

Regardless of type, a primary recognition feature is the lee slope, which

remains virtually constant at approximately 61°, which corresponds to the angle of repose of dry sand (34 degrees). However, this feature is valid only for active dunes; in fixed dunes (i.e. those covered with vegetation) the characteristic lee slope can be so altered as to be unrecognizable, as is illustrated in figs. 15 and 17.

147. Local erosion. Water erosion normally does not occur, because infiltration and internal drainage are so good that surface flows cannot exist. However, dunes which have been fixed so long that a topsoil of less permeability has developed occasionally display V-shaped gullies with very steep gradients.

148. Dunes are, of course, exceedingly susceptible to wind erosion. All active dunes owe their shape to a combination of eolian erosion and deposition. Any break in the vegetation cover of fixed dunes may result in rapid eolian erosion, the normal pattern being a smoothly rounded hollow bounded on the downwind side by an active dune of some type, as illustrated in figs. 17 and 18. These areas, called "blowouts," almost always photograph in brilliant white tones, contrasting sharply with the gray tones of the fixed dunes.

149. Natural vegetation. Even areas of active dunes are rarely entirely devoid of vegetation. Note that the obviously active dunes illustrated in fig. 16 actually support a few scattered shrubs. In addition, the sandfree areas between the dunes (the so-called "gassi plains") commonly support thin growths of grass or shrubs. However, the overwhelming impression is one of extreme barrenness. The vegetation of fixed dunes is to a considerable extent controlled by the climatic regime in which they occur. However, the excellent internal drainage results in a general lack of soil moisture, so that dunes tend to be grass-covered even when adjacent areas of other soil types are tree-covered. Furthermore, the vegetation of fixed dunes is somewhat irregular, so that even when grass-covered the resulting textures are finely mottled or flecked, as illustrated in fig. 17. When the dunes are tree- or scrub-covered, as in fig. 18, the vegetation coverage is normally much less dense than on adjacent nondune areas. The result is a much lighter tone of gray and an emphasis of the finely mottled or flecked textures.

150. Land use. Many dune areas, especially those composed of active

dunes, betray no trace of agricultural or other cultural modification. The land use in areas of fixed dunes is to a considerable extent dictated by the climate. In humid and subhumid climates, dune areas are frequently used as pastures, with field boundaries independent of topography. This use is illustrated in fig. 17; note that the variations in tone between adjacent fields are relatively indistinct. Where temperature is suitable and rainfall adequate, orchards are not uncommon. In regions where isolated fixed dunes are distributed over surfaces of more fertile soil, the field boundaries pass indiscriminately across the dunes, as illustrated in fig. 15. However, the typically sparse vegetation cover, coupled with the very light color of the dune sand, results in a much lighter photo tone for the dune than for the surrounding areas. In such regions, where cultivation is intense, dunes are commonly used as either pasture areas or as wood lots (see fig. 15), which contrast sharply in both tone and texture with the smoothly cultivated adjacent fields.

151. Construction practices. Dunes, especially along sea or lake coasts, usually are used as resort areas if they occur near large population concentrations. In such cases, the typical structures and recreational facilities of resort areas, as illustrated in fig. 18, will occur. Pit excavations from which sand is removed for building materials or other industrial purposes can normally be recognized by the associated buildings and machines. The presence of such works usually indicates relatively clean quartz sand.

152. Parent material. Dune sands are usually uniform in grain size. In general, about 90% of the material passes the No. 40 sieve (0.42 mm), and from 20 to 10% passes the No. 200 sieve (0.074 mm). However, important exceptions to this generalization occur. For example, the fixed dunes of Lincoln County, Nebraska (see fig. 17), are composed of sands considerably finer than normal, and they also contain a substantial percentage of silt; this dune area is transitional between an area of more normal dunes and a region of loess, and would thus be expected to retain some of the characteristics of both.

153. Most dunes are composed chiefly, and in many cases almost exclusively of quartz sand. However, as with grain size, important exceptions occur. The sands of the fixed dunes of Umatilla County, Oregon, are

derived from basic lavas, and are accordingly dark and glauconitic. These sands are also much finer than normal, because the dark minerals of which they are composed are heavier and therefore more difficult for the wind to move. The sands of the large dune fields of White Sands National Monument, New Mexico, are composed almost exclusively of gypsum; the grain size is abnormally large because gypsum is relatively light and thus readily moved by the wind.

154. Soil profile characteristics. Active dunes have no developed soil profiles; the materials are essentially uniform from the surface to the base of the dune. The soils of active dunes are almost invariably of SP type. Fixed dunes normally have a developed soil profile, although it is commonly indistinct. Fixed dunes generally have soils classified as SP, SP-SM, or SM, with SM soils being most common where the dunes have been fixed for a long time. Dune areas being used agriculturally commonly have soils of this type. Low topographic positions in fixed dunes in some instances contain minor amounts of organic material, and there is not uncommonly a considerable concentration of fine-grained materials of varying depths below the surface. Low topographic positions in dune areas may also have high water tables during wet periods.

155. The density of the sands on active dunes varies considerably depending on topographic position and position relative to the prevailing wind. Very low densities in general occur on the lower slopes of the windward face, and on the entire lee slope, whereas relatively high densities normally occur along a line 1 to 2 ft back from the crest and extending partway down the windward slope. These differences are not evident in fixed dunes; the sands of such dunes are in general slightly more dense than the densest areas of active dunes.

156. Trafficability and cross-country movement characteristics. Soil tests were made in seven states in climatic regimes ranging from cool to warm, and from very humid to arid (see Appendix B). Of the 26 sites tested, 10 were topographically low and 16 were topographically high. The 25 coarse-grained soils exhibited no apparent correlation between high and low sites, or between soil type and climatic regime. The single fine-grained soil tested (ML) was in a low site in a cool, dry climate.

157. The majority of the soils tested (62%) were in trafficability

class A (SP), and the remainder (38%) were in class D (SM, SP-SM, ML). The CI values for the SP soils ranged from 16 to 233 with the majority of site averages falling between 80 and 100. The site with the low value of 16 would be trafficable to tracked vehicles since they would compact the loose sand with traffic, but wheeled vehicles would immobilize at normal tire pressures and perhaps have some difficulty at low tire pressure. All RCI values for the class D soil were high; they ranged from 138 to greater than 300. This soil would be trafficable to all vehicle categories if the wheeled vehicles are operated at low tire pressure in areas where the surface sand is dry and loose.

158. The soils are so cohesionless that vehicles would have difficulty obtaining traction, even on relatively modest slopes. This factor alone makes the lee slopes of active dunes virtually unclimbable by any military vehicle. Wheeled vehicles operating at high tire pressures (40 psi and greater) find the going difficult if not impossible in the generally loose sands of the interdune areas, even though slopes are negligible. Vehicles operating at low tire pressures (10 to 15 psi) are much more mobile in dune sands than when operating at high tire pressures, and tracked vehicles normally have little difficulty except on the lee slopes. Dune sand usually gains strength with successive vehicular passes, because tire or track action tends to pack loose sands.

159. In those interdune areas where silts have concentrated, and where the water table is close to the surface (i.e. within 2 ft), soil strength (RCI) may be so low that even tracked vehicles may be immobilized. This condition is most common in areas of fixed dunes, but it may, in some instances, occur even in active dunes.

Loess surfaces

160. Large loess areas (see fig. C2, Appendix C) occur in the United States in Mississippi, Illinois, Iowa, Kansas, Nebraska, and Washington. The material is apparently related to large streams such as the Mississippi, Missouri, and Snake Rivers. Elsewhere in the world, extensive areas of loess occur in Argentina, across central Europe and extending into southern Russia, and across south central Asia and into northern China. Loess is exceedingly variable in thickness, varying from a few inches to over 200 ft in a few places. In general, it must be several feet thick before

it produces a distinctive landscape pattern. There is no correlation between loess and the materials on which it lies.

161. Regional drainage. The gross drainage pattern is usually dendritic, sometimes with a rough tendency toward the parallel type, but low-order drainage is normally distinctly pinnate, as illustrated in fig. 19. Loess regions are virtually unique in the excellence of development of the pinnate pattern; it therefore constitutes a primary recognition feature.

162. Topography. Loess regions are commonly characterized by blocky cross-sectional shapes with local relief ranging from 3 to about 150 ft. In some regions, such as parts of Iowa and Mississippi, erosion has proceeded to such a point that the cross-sectional shape is chiefly a crested type, with only traces of blocky uplands remaining. For an illustration of this type, see fig. 19. The slopes of the valley walls are very steep, in some places reaching 100% or more, while the valley floors tend to be very flat (see fig. 20).

163. Local erosion. Erosion by running water is singularly effective in loess regions. Gullies are generally of the F type (see table 5), although this is to some extent dependent upon climate and vegetation cover. In humid and subhumid regions (see fig. 20) the distinctly F-type gullies tend to terminate in amphitheater-like hollows bounded by vertical walls. In arid and semiarid climatic regimes this type gully shape is more obscure, and the smaller gullies may tend toward the V type. The gradients of the gullies are normally low. Rill erosion may be intense on unprotected slopes.

164. Natural vegetation. In humid climates, loess areas are normally covered by dense forest. However, loess drains so rapidly that the soil environment becomes semiarid more rapidly than for many other soil types; as a result, the trees tend to give way to grass cover while the "meteorological climate" is still relatively humid. Loess areas in Kansas, Nebraska, and Washington tend to be remarkably devoid of trees even along drainage channels.

165. Land use. Cultural practices, like the natural vegetation, tend to be dominated by the climatic regime. The normal pattern in humid environments is illustrated in fig. 19; valley slopes are covered with trees and the undulating or rolling ridgetops (and commonly the flat valley

bottoms as well) are cultivated. The field outlines tend to be very irregular. This pattern of vegetation distribution emphasizes the pinnate drainage pattern, but obscures the typical F-type gullies. In subhumid environments, the steep valley slopes are usually grass-covered, as illustrated in fig. 20. Here, as in humid climates, the undulating or rolling ridgetops and the flat valley bottoms are cultivated; note the ribbon-like valley bottom cultivation in fig. 20. In semiarid regions, especially in those where gullying is not intense, field boundaries tend to cross the drainage pattern indiscriminately. The nature of the crops grown on loess is also markedly climate-controlled. In warm-humid climates, crops tend to be corn, cotton, or other row crops, resulting in a linear texture, whereas semiarid and subhumid area crops tend to be grain and forage, resulting in a smooth texture. However, even in humid regions the narrow ridgetops are used as pasture, resulting in the smooth texture typical of sod-forming grass, as illustrated in fig. 20. On the other hand, the somewhat irregular grass stands of transitional climatic types result in a very finely mottled or flecked texture, which contrasts sharply with the generally lighter tones and smoother textures of the cultivated fields. Orchards, displaying the typical grid pattern, are not uncommon on loess in areas where moisture is adequate and temperature appropriate.

166. Construction practices. Where local relief is considerable, secondary roads tend to follow the ridge crests and, when crossing a valley, follow circuitous routes, as illustrated in fig. 19. In regions of lower relief, the roads tend to be independent of topography. Road cuts commonly display near-vertical banks, as shown in fig. 20. They tend to show very smooth and regular edges, especially when new, as opposed to rock cuts, which display serrate or irregular edges.

167. Parent material. Loess is an unconsolidated material composed chiefly of silt-size particles, with minor amounts of very fine sand and clay, and in certain areas may exhibit a relatively high (up to 16%) calcium carbonate content. The unique ability of loess to stand in vertical cliffs is a result of its peculiar structure in the undisturbed state; once the structure is destroyed, the material largely loses this property. The presence of calcium carbonate may control the duration of slope stability in very steep slopes.

168. Soil profile characteristics. The soil profiles that form on loess surfaces are, like their parent materials, remarkably uniform, although they vary mineralogically to some extent, depending upon the source of the parent material. In general, more than 90% of the particles pass the No. 200 sieve (0.074 mm). The soil is generally classified as either ML or CL under the USCS and as a silt loam according to the USDA classification. These classifications are in general independent of topographic position, but occasionally a basin will accumulate enough organic material and clay to develop an OL or OH soil type. The soil profiles on high topographic positions commonly consist of 6 to 12 in. of slightly organic silty topsoil underlain by unaltered parent material. The profiles of soils in low topographic positions (especially in the northern half of the United States) commonly consist of 12 to 24 in. of slightly organic silty topsoil underlain by variable thicknesses of mottled gray-brown silty material. Organic topsoils may be deeper and more plastic in the northern prairie regions (i.e. where grasses, forage, and grain crops are grown).

169. The soils of loess regions tend to drain so readily that the surface dries rapidly; the combination of the characteristic light brown color and lack of moisture results in light gray to almost white tones on photographs.

170. Trafficability and cross-country movement characteristics. Of the 40 sites that were classified as to soil type (see table 3), 3% were in trafficability class B (CH), 47% in class C (CL, GM), and 50% in class D (ML, CL-ML, OL, OH). Of these, the CL type accounted for 45% and the ML for 38%; both were about equally divided between high and low topographic positions. The CL-ML, OL, and OH soils were found only in low positions, whereas the single CH soil was on a high site and the single GM soil on a low site. There appears to be no correlation between soil type and climatic regime.

171. The trafficability class C soils exhibited a difference in RCI values as a function of topographic position. The low sites were less trafficable than the high (average RCI 157+ vs 132). The RCI of the C soils ranged from 71 (trafficable for the category 1-4 vehicles listed in paragraph 27, marginal for category 5) to over 300 (trafficable for all vehicles), with most sites exhibiting values above 100.

172. The ML component of the trafficability class D soils appeared to be trafficable for all vehicles except category 7 regardless of site; the RCI values ranged from 94 to over 300. Ten of the ML sites were located in high topographic positions and five were located in low topographic positions. However, both OL and OH components exhibited RCI values of about 62, which implies that they would be trafficable only for category 1, 2, and 3 vehicles. These soils were confined to low sites where soil moisture content tends to remain high; they could thus be expected to exhibit poor trafficability during wet periods. Such areas can usually be identified on airphotos by the combination of topographic position and dark photo tones.

173. The major obstacles to movement in loess regions are the steep valley and gully slopes. These are commonly in excess of 70%, and are thus too steep for any military vehicle to negotiate even under ideal soil conditions. Where dissection is severe, vehicular movement is for all practical purposes confined to the ridgetops and the valley bottoms. Movement across the "grain" of the drainage pattern is very difficult or impossible. In humid regions the dense forests which cloak the valley sides may also inhibit or prevent movement.

Landscapes in Glacial Materials

174. These landscapes are considered in this report to be only those features which formed either in direct contact with the ice mass, or so close to it that the forms were to some extent controlled by its presence. These features include ground moraines, ridge moraines of various types, drumlins, eskers, and kames.

175. Glacial deposits are among the most diversified in nature. They are infinitely variable in mineralogy and grain size, and only slightly less variable in thickness and surface configuration. In fact, their very diversity is in some instances an important recognition feature. Glacial deposits may range in thickness from a few inches to as much as 600 ft, and this range may occur in amazingly short distances. Grain size ranges from clay to boulders many feet in diameter; it is not unusual to find the latter embedded in the former. Surface configurations range from

virtually featureless, nearly plane surfaces to rugged hills and sharply crested ridges, with the transition from one to another being in many cases very sharp.

176. There is no essential correlation between the nature of the bedrock and the character of the overlying glacial deposits. However, this generalization must be somewhat modified in certain instances. For example, in regions where a single type of rock occurs over a large area, and especially where the glacial deposits are relatively thin, the soil materials are often derived chiefly from the underlying bedrock. In spite of this, contacts between various rock types have been so badly blurred in many places by the mechanisms of glacial transport and deposition that the nature of the bedrock should be inferred from the soil characteristics alone only when all other data are lacking.

177. Glacial deposits of different ages may differ markedly in characteristics, even though the mode of deposition is similar. Several reasons contribute to this variation. First, the surface configuration of the two deposits may differ because of the difference in time available for erosion. Second, the parent materials may differ both mineralogically or in texture because the points of origin and directions of movement of the glacial mass of the two periods may have been different, and accordingly the parent materials may have derived their transported load from different types of rock or soil. Third, the differing periods available for the weathering or retransport of the parent materials may result in different properties.

178. In the midcontinent region of North America these differences have resulted in clear-cut distinctions between an older drift sequence (the Illinoian) and a younger sequence (the Wisconsin). Unfortunately, these same distinctions are not necessarily evident in other parts of the world, with the result that they should not be applied elsewhere without due caution.

Old ground moraines (Illinoian stage)

179. Ground moraines of this type are limited to portions of southern Ohio, Indiana, and Illinois. The morainic material is normally from 20 to 60 ft in thickness, but in many places the larger streams have cut through the entire glacial deposit and flow in bedrock channels.

180. Regional drainage. Both the gross and low-order drainage patterns are generally dendritic. However, in places where the glacial drift is very thin, the low-order drainage patterns may be obviously rectangular as a result of control of the channels by joint systems in the underlying bedrock.

181. Topography. The cross-sectional shape is undulating, normally with local relief of only a few feet, or a few tens of feet at the most. The visual impression is one of a very gently undulating plain, as illustrated in fig. 21. Slopes rarely exceed 5 or 10%.

182. Local erosion. Gullies are C type, being very broad and shallow and having very low gradients. The sides of both gullies and stream channels tend to photograph in tones much lighter than the adjacent uplands and lowlands, indicating extensive sheet and/or rill erosion, as illustrated particularly in the upper third of fig. 21. This feature may occur where an impermeable subsoil underlies a permeable topsoil.

183. Natural vegetation. Natural vegetation on ground moraines was chiefly dense forest; however, such areas are now so intensively cultivated that little or no trace of the original vegetation remains.

184. Land use. Field patterns are generally rectangular, and tend to cut indiscriminately across the topography. Crops are diversified, with the result that fields photograph in a wide range of tones, although almost all show at least a trace of linear texture, the result of plowing practices or growing row crops. The practice of plowing so as to form "dead furrows" (i.e. an occasional furrow both deeper and wider than usual) is common, chiefly because it assists in draining the flat fields. This practice results in a relatively coarse-grained linear texture on airphotos, as illustrated in fig. 21. Scattered wood lots occur, and they are easily recognized on the photographs because of their botryoidal texture and darker tone. They are generally rectangular in outline and relatively widely spaced, but they become increasingly irregular and more numerous with decreasing thicknesses of glacial deposition.

185. Construction practices. Roads are independent of topography or drainage. Construction in rural areas is confined almost entirely to clusters of farm buildings.

186. Parent material. The parent materials are exceedingly variable,

consisting of complex mixtures of clay, silt, sand, and some gravel. These materials vary in random fashion both horizontally and vertically.

187. Soil profile characteristics. The A-horizon of the soil is generally either CL or ML; it is normally friable and about 2 ft thick. The friability is often revealed in photos by the evidence of widespread removal of surface soils by erosion, as indicated in paragraph 182. The B-horizon is generally of CL type and is about 11 ft in thickness. This silty clay layer is relatively cohesive and impermeable, and is responsible for the typically saucer-shaped gullies. The light gray "fringe" that so commonly borders these gullies is produced by the partial or complete removal of the surface soil layer, revealing the light-colored subsoil. This effect is frequently enhanced by lack of vegetation cover on the gully sides, permitting the bare soil to show through.

188. The topographically low areas have soils which are both siltier and more organic (types ML and OL) than those on high topographic positions, the latter being chiefly CL types of low plasticity index.

189. Trafficability and cross-country movement characteristics. The 6- to 12-in. soil layer on topographically high positions had an average CI of 100 during the wet season, and the average for the same layer in the soils of low positions was 61. The high soils fell into soils trafficability class C, while those in low positions fell into class D. The soils in low positions, being siltier, will have a lower RI and will consequently lose a more substantial portion of their ability to support traffic during periods of high moisture content (i.e. during the wet season) than those on high positions. The estimated RCI for soils in high positions during the wet season is from 70 to 100, and that for soils in low positions, 40 to 80.

190. The estimated RCI values suggest that most, if not all, high sites will be trafficable for category 1-4 vehicles during the wet season, and for all vehicles during the dry season, except for a few days after a soaking rain. The low sites would probably be trafficable during the wet season for only category 1 and 2 vehicles; and even in the dry season, they would probably be marginal for category 7 vehicles, although passable for other categories. Further, the low sites drain so slowly that they would gain strength only after relatively long periods even in the dry season.

191. During the dry season (i.e. when soil moisture is low) the

gullies probably would not be an obstacle to cross-country movement. Side slopes are in general so gentle that they are readily climbable by military vehicles. However, during the wet season the combination of lowered soil strength, slipperiness, and even gentle slopes may result in a serious obstacle, especially close to major drainage lines where the gullies are deeper.

Young ground moraines (Wisconsin stage)

192. This type of ground moraine is widely distributed in North America; examples occur in virtually every state north of the Ohio and Missouri Rivers. The deposits vary in thickness from a few inches to several hundred feet, and in many places the larger streams have cut entirely through the glacial deposits and flow in bedrock channels.

193. Regional drainage. The gross drainage pattern is chiefly dendritic, but kettle-hole and deranged patterns occur in many places, as illustrated in fig. 22. Low-order drainage patterns are commonly dendritic, or crudely developed centripetal types around kettle lakes. In many places the drainageways are widely spaced and poorly developed. Both surface and internal drainage are so poor in many places that it has been necessary to improve them by either ditches or tiles or both.

194. Topography. The cross-sectional shape of this type is somewhat variable. The most common expression is undulating. It differs from old ground moraine chiefly in that it generally contains undrained basins, and gives an overall visual impression of greater randomness. In general, the local relief is very small, and rarely exceeds a few feet or few tens of feet. A few notable exceptions occur, chiefly close to major streams; in such places the combination of thin glacial deposits and rugged bedrock topography may produce surfaces of abnormally high relief. Except in such places, slopes rarely exceed 5 to 10%.

195. Local erosion. Perhaps the most common type of gully is that illustrated in fig. 22, broad and C type with very flat gradients. Other young ground moraine areas, however, may have few or no gullies, as illustrated in fig. 23. There is a crude correlation between those types with few or no gullies and kettle-hole or deranged surface drainage patterns. Sheet erosion is normally extensive regardless of gully type, and is indicated on the photographs by the light gray hilltops in figs. 22 and 23.

The combination of sheet erosion and poor surface and subsurface drainage results in the typically mottled pattern (or texture) illustrated in fig. 22. This pattern occurs frequently in humid climates.

196. Natural vegetation. Young ground moraines are almost entirely under cultivation.

197. Land use. Field boundaries are normally rectangular and generally pass indiscriminately across both drainage and topography. In the more humid regions (e.g. the Great Lakes states), the crops are diversified, with resulting wide differences in photo tone and texture, although there is generally at least some trace of a linear texture developed as a result of plowing and cultivation, as illustrated in fig. 22. In the humid areas, the presence of numerous wood lots or even forest tracts commonly indicates sandy soil. In the subhumid regions, there is a notable lack of trees. The presence of "strip farming" (i.e. alternating strips of crop and fallow, or grains and row crops, as illustrated in fig. 23), especially in the subhumid regions, normally implies the presence of noncohesive sandy or silty soils that are subject to wind erosion.

198. Construction practices. Roads normally are independent of drainage or topography. Fields may be ditched and/or tilled in some regions to improve drainage. In rural areas, other construction is generally limited to clusters of farm buildings, as illustrated in figs. 22 and 23.

199. Parent materials. The parent materials are highly variable both vertically and horizontally. In the states adjacent to the Great Lakes the most common type is a "till" (i.e. a heterogeneous mixture composed of clay and silt with varying admixtures of sand and gravel), whereas in the Great Plains states, the most common parent material is considerably coarser, in some places being chiefly sand and gravel with minor amounts of silt and clay. There is a general correlation between parent material type and both topographic expression and drainage pattern. In general, basined surfaces or deranged drainage patterns imply coarse-grained materials, and valleyed surfaces and dendritic drainage patterns imply fine-grained materials.

200. Soil profile characteristics. The surface soils of this type of landscape are widely variable, depending chiefly upon the random nature of glacial deposition, topographic position, and to some extent the

climatic regime under which they developed. In general the A-horizon of the soils is approximately 1 ft thick, with the B-horizon being widely variable in thickness but seldom exceeding 4 ft.

201. In general, the soils of high topographic positions are of CH and CL types, regardless of climatic regime, although notable exceptions occur. For example, ML soils are relatively common on high topographic positions throughout the range of this landscape type. Throughout the range of this landscape type the plasticity of the soil tends to increase with depth. Soils in the subhumid regions (i.e. those developed under prairie conditions) tend to be somewhat more plastic than those of the humid regions, perhaps because their organic content tends to be more conducive to the development of clay minerals.

202. In general, the soils of low topographic positions are somewhat organic and tend to be of OL and OH types, regardless of climatic regime, although exceptions occur. For example, both ML and CL types occasionally occur in low positions. Peats and mucks (Pt) can also occur in low positions. The soil horizon containing organic material is in general less than 12 in. thick, but in some cases is as much as 18 in., and in kettle depressions may be several feet or even yards. The B-horizon is commonly a moderately plastic inorganic soil of CL or CH type.

203. The contrast between high and low topographic positions is usually strikingly displayed by variations in tone on the photographs. The organic and silty or clayey soils of the low positions are both darker in color and hold moisture longer than the slightly more coarse-grained soils of the high positions; they therefore photograph dark, resulting in the typical mottled pattern or texture illustrated in figs. 22 and 23.

204. Trafficability and cross-country movement characteristics.

Only about 10% of the 51 sites tested had soils in trafficability class B (CH), and these occurred about equally in high and low positions. However, about 31% of the areas tested comprised soils in class C (CL), and these, with two exceptions, occurred on high positions. Soils of trafficability class D (ML, OL, and OH) comprised about 59% of all soils tested. In general, these soils tended to occur in low positions, although many exceptions occurred. For example, the ML component of this class apparently occurs most frequently on high positions, although the number of tests made

is inadequate to firmly establish this relation. Only one site tested, a low site in Minnesota, was in class E (Pt); however, this soil type probably occurs in appropriate topographic locations, such as kettles, in all of the states in the northern tier.

205. The soils of this landscape type may approach or reach field capacity during the wet season regardless of topographic position and, in this state, not only lose a substantial proportion of their strength but become sticky as well. Several sites showed a strength loss of 45% in the 6- to 12-in. layer during the wet season, and one site (in Ward County, South Dakota) in a low position lost 68% of its strength. The soils of high positions retained approximately 27% more of their strength than those of low positions.

206. The RCI data suggest that high sites (average RCI 109) will be trafficable for all vehicle categories regardless of season, although the going may be difficult in a few places. The wet-season data available for low sites (average RCI 61), however, suggest that they will be trafficable for category 4 vehicles, but many places will be marginal for category 2 vehicles. Further, soils in low areas may remain wet even during the dry season. Such locations commonly have water tables within 2 ft of the surface. When this condition occurs, low areas may be untrafficable regardless of season. Slopes are generally so gentle that they do not constitute obstacles when soil moisture levels are low. However, a combination of high soil moisture and the steeper slopes may constitute obstacles to many military vehicles.

Ridge moraines

207. As used in this study, a ridge moraine is an accumulation of glacially deposited materials that forms a band or belt of hills or ridges that rise appreciably above the adjacent landscape. It includes both terminal and lateral moraines. These landscapes are exceedingly variable in both surface expression and internal composition. The same morainic system may exhibit several variations in shape and parent materials within the space of a few miles. However, there is a crude relation between parent material type and geographical location. Those near the outer boundary of glacial deposition (i.e. near the Ohio and Missouri Rivers) tend to be composed of finer-grained materials than those which occur farther north.

208. Regional drainage. The gross drainage pattern is normally dendritic, but the basic pattern can be interspersed with kettle-hole, deranged, or even drainageless areas. The spacing between drainageways is widely variable, ranging from very wide to very close, sometimes in adjacent areas. Large morainic masses may also exhibit radial or parallel gross drainage patterns, although such patterns are usually relatively weakly developed. Low-order drainage patterns are commonly dendritic, but well-developed radial patterns may occur around individual topographic highs, and crude parallel patterns are not uncommon on the flanks of ridges.

209. Topography. Where the parent materials are coarse grained, the cross-sectional shape is usually crested, and basins are relatively frequent, although frequency varies widely from place to place. Slopes are generally fairly steep, and in some cases reach approximately 60%. The moraine illustrated in fig. 24 is relatively coarse grained. Note the small kettle at the intersection of the marginal arrows. Where the parent materials are finer grained, the cross-sectional shape is rolling, and slopes rarely exceed 40%. Local relief of ridge moraines may range from 20 to about 200 ft with the coarser-grained varieties tending to exhibit more visible relief.

210. Local erosion. Where the parent materials are generally coarse grained, gullies are V type with steep gradients. In some places, where coarse-grained parent materials exhibit such excellent internal drainage that surface flows do not develop, even relatively steep slopes may show no trace of gullying. In some places where the vegetation has been completely destroyed, there may be evidence of wind erosion, including deflation hollows in rare instances. Where parent materials are finer grained, the gullies tend to be more C type and to have flatter gradients. In such materials, road cuts and bare fields display evidence of rill and sheet erosion.

211. Natural vegetation. Moraines in humid climates are, in general, tree-covered. Where the parent materials are coarse grained and internal drainage is good, the rapid loss of soil moisture results in relatively open woodlands and, in extreme cases, open grasslands with only an occasional tree. This condition is illustrated in the right center of fig. 24. In subhumid climates, the vegetation of moraines is

normally grass, with trees only in the wetter ravines and valleys.

212. Land use. Where the parent materials are coarse grained, normally only scattered fields are cultivated; the remainder of the land is generally used as pasture or timberland, as illustrated in fig. 24. Field boundaries are to a considerable degree independent of topography or drainage, but frequently, as in the area illustrated in fig. 24, the field shapes are partially controlled by topography. The fields generally photograph in strikingly light tones and smooth textures, as opposed to dark tones and botryoidal or flecked textures of the forests and savannas. Where the parent materials are finer grained, much more of the surface is normally cultivated, with field patterns being essentially independent of topography. The crops in such areas are normally diversified, resulting in widely different tones and textures between adjacent fields. In many places the fields have been terraced to control gully and sheet erosion.

213. Construction practices. Roads tend to cross moraine systems on slightly sinuous paths, as illustrated in fig. 24. Road cuts generally have steeper banks where parent materials are coarse grained than in areas where the materials are fine grained. Where materials are fine grained, the road embankments commonly show evidence of rill erosion. Gravel and sand pits are relatively common in moraines where materials are coarse grained.

214. Parent materials. The parent materials of this landscape are generally heterogeneous mixtures of sand, gravel, and silt. However, almost pure sands occur in some places, while in still others the materials may be predominantly cohesive clays and clayey silts. Virtually all possible combinations occur, with the nature of the materials varying rapidly both vertically and horizontally. There is a rough correlation between the grain size of the parent materials and the geographic location, with finer materials occurring near the outer margin of glaciation, and coarser materials tending to occur toward the inner zone. There is also a general relation between drainage types and grain size of the parent materials. Very wide spacings between drainageways, the local presence of deranged patterns, and an abundance of kettle holes generally indicate coarse-grained materials. The complete absence of drainageways normally indicates very sandy or gravelly parent materials. The spacing of drainageways is generally

much closer in fine-grained materials, and areas of deranged and kettle-hole drainage are much less extensive or may be completely absent.

215. Soil profile characteristics. Because of the significant differences between the soil characteristics of moraines close to the southern limit of glaciation and those farther to the north, the two areas are separated in the following discussion.

- a. Moraines chiefly in Michigan, Wisconsin, and Minnesota. Of the 29 sites sampled in this area, 25 exhibited soils in the 6- to 12-in. layer in the coarse-grained classes (SP, SC, SM, SM-SC, SP-SM), while the remaining 4 exhibited fine-grained soils. The depth of alteration (i.e. the A-horizon plus the B-horizon) is usually less than 4 ft but may be up to about 7 ft in some places, especially in topographic lows. On high topographic positions the A-horizon is from 3 to 12 in. thick, with the B-horizon from 2 to 4 ft thick. Generally the B-horizon contains a slightly higher proportion of clay-size particles, thus having a slightly higher plasticity than the A-horizon. On low topographic sites the proportion of fine-textured materials tends to be somewhat higher than in the adjacent topographically high soils, probably because of concentration of fines due to sheet erosion. On low sites the depth of weathering is also somewhat greater; the A-horizon is normally from 6 to 18 in. thick (except in areas of high organic content, in which case it may be several feet thick), while the B-horizon is from 3 to 6 ft thick.
- b. Moraines chiefly in Indiana. All of the 8 sites examined in this area exhibited fine-grained (CH, CL, ML, and OH) soils in the 6- to 12-in. layer. The depth of alteration is normally 7 to 8 ft, with a few as much as 10 ft. The A-horizon on the topographic highs is normally 6 to 12 in. thick, with the B-horizon 3 to 6 ft thick. The A-horizon in the topographic lows is usually less than 2 ft thick, while the B-horizon is usually from 4 to 6 ft thick, and as much as 10 ft thick in a few places. The B-horizons in both topographic low and high positions tend to be slightly finer grained than the A-horizon, but the distinction is much less obvious than in the ridge moraines farther to the north.

216. Trafficability and cross-country movement characteristics.

- a. Moraines chiefly in Michigan, Wisconsin, and Minnesota. Of the 29 sites tested 25 were coarse-grained soils of which 13 were high and 12 were low topographic positions. The coarse-grained soils included soil trafficability classes A (SP), C (SC), and D (SM, SM-SC, SP-SM), with by far the larger number (21 out of the 25) occurring in the latter class. Also, the majority of class D soils were sand mixed

with silt (SM). There is no apparent correlation between topographic position and soil trafficability class. Most of the soils tested were trafficable for all vehicle categories. However, SM and ML soils in low topographic positions retained relatively higher moisture contents than the soils of high sites, and were accordingly somewhat weaker. The most notable examples were those in undrained basins or poorly drained channels; these soils tend to be highly organic, with water tables close to the surface. Two such sites resulted in RCI's of 32 and 45. These sites would be trafficable only for category 1 vehicles, and marginal for category 2 vehicles. CI for the clean sand (SP) in low topographic position was also low (average 45). These areas would be difficult to traverse with conventional wheeled vehicles at high tire pressures.

Moraines of this type commonly have steep slopes, in a few places as much as 60%. Sandy soils would also present traction difficulties. Further, the flanks of the morainic ridges may be scarred by steep-sided gullies. The combination is sufficient to result in serious impediment to cross-country movement. Movement in many places would be still further impaired by the tree growth so common on moraines of this type; although the trees are generally so far apart that they can be avoided, the resulting routes are very circuitous.

- b. Moraines chiefly in Indiana. Of the fine-grained soil sites tested, 5 were in low and 3 in high topographic positions. They include soil trafficability classes B (CH) and C (CL), with 7 out of the 8 sites in class C. All the soils tested were trafficable for category 7 vehicles during the wet season. RCI was slightly greater for the high topographic sites (171 vs 153). Although the test data reported indicate sufficient bearing capacity when wet, these soils will exhibit stickiness and slipperiness characteristics. Wheeled vehicles without special traction devices such as chains may become immobilized.

Slopes in moraines of this type rarely exceed 40% and do not pose a serious obstacle to movement except during the wet season. The ravines are generally saucer-shaped and negotiable, although with some difficulty. Slipperiness on slopes will be a major problem. Vegetation is normally not an obstacle.

Kettle-kame moraines

217. As described in this report, kettle-kame moraines are any accumulations of glacial deposition that result in landscapes that rise appreciably above the adjacent terrain, which are generally not arranged in linear bands or belts, and which are composed of crudely stratified parent

materials. The division between kettle-kame moraines and ridge moraines is an entirely arbitrary one; in nature they grade into each other. Kettle-kame moraines occur in scattered regions throughout areas which have been subjected to glaciation, although in the United States they are rarely if ever found near the extreme southern limit of the glaciated area (i.e. near the Ohio and Missouri Rivers).

218. Regional drainage. The gross drainage pattern is chiefly of the kettle-hole type, but perhaps the most striking characteristic is the almost complete absence of developed scour channels over fairly large areas, as illustrated in fig. 25. Where integrated drainage patterns do occur, they are generally of the deranged type. Small lakes, swamps, and marshes of widely variable shape and size are common, and are generally more numerous than in ridge or ground moraine landscapes. Low-order drainage patterns are generally weakly developed dendritic or centripetal.

219. Topography. The cross-sectional shape is almost invariably rolling, as illustrated in fig. 25. The local relief normally ranges from about 40 to 100 ft. Inclosed basins, the so-called "kettles," are very numerous, and the intervening uplands normally consist of subconical hills and short, discontinuous, and irregular ridges, as illustrated in the upper left corner of fig. 25. A typical kame is illustrated by the marginal arrows labeled B in fig. 27. This type of surface is frequently referred to as "hummocky" topography. Slopes are widely variable, and may range up to as steep as 60%. The overall visual impression is one of extreme randomness.

220. Local erosion. Gullies are rare or absent. Where they do occur, they are almost invariably V type with steep gradients. Their presence generally indicates a somewhat cohesive topsoil underlain by noncohesive materials. In some places, where vegetative cover has been destroyed and the soil materials are appropriate, eolian erosion occurs, resulting in "deflation basins" and the so-called "sand smears" (i.e. irregularly shaped areas having appreciably lighter photo tones than the adjacent areas), as illustrated in fig. 25.

221. Natural vegetation. The uplands of most kettle-kame moraines are now so completely modified by cultural practices that little or no trace of the natural vegetation remains. In humid areas the uplands were

chiefly covered by forest consisting of relatively widely spaced trees. In subhumid regions the moraines were chiefly grass- or scrub-covered, with trees present only in sheltered hollows. Natural vegetation, or a close approximation thereof, still occurs in the undrained hollows. In such places a striking vegetation pattern is commonly displayed. In general, it consists of a series of concentric bands, the outermost being trees or shrubs. Immediately inside is a band consisting of reeds, tall grasses, and sometimes shrubs. This band can normally be readily differentiated from the tree band that usually rings an open pond or lake, or from a band of very light-toned and low-lying vegetation ringing an open pond. Local variations produce an almost infinite number of variations on this general theme, several of which are illustrated in fig. 25.

222. Land use. In humid regions most landscapes of this type are more or less intensively cultivated. The field boundaries are generally rectangular, but they are normally somewhat modified by topographic or drainage considerations, as indicated in fig. 25. Irregular wooded areas are common, and are readily identifiable by their generally dark tone and botryoidal texture. The kettles may or may not be cultivated, depending upon the internal drainage of the soil. Where such drainage is good, the kettles are generally cultivated, as is illustrated in fig. 25 at the intersection of the marginal arrows labeled A. If internal drainage is poor, the kettle may not be cultivated, even though it contains no open water. The example indicated by the marginal arrows labeled B in fig. 25 is a case in point. Such kettles normally have highly organic soils and water tables within a few inches of the surface, regardless of season. The crops are normally diversified, resulting in wide and sometimes startling differences in both tone and texture, as illustrated in fig. 25.

223. Construction practices. Road alignments are basically rectangular, but in most areas at least some of them have been forced into sinuous paths to avoid steep slopes or kettles. Road cuts commonly display side slopes of approximately 60%, as is illustrated at the intersection of the marginal arrows labeled C in fig. 25. Gravel and sand pits are present; their presence is an indication of relatively clean sand or gravel. In rural areas, clusters of farm buildings occur. In some places there is relatively elaborate recreational construction on the shores of the larger

kettle lakes. A small development of this type occupies the peninsula in the lake in fig. 25.

224. Parent materials. The parent materials of kettle-lake moraines are chiefly relatively clean, crudely stratified sands and gravels. However, there is an appreciable variation within relatively short distances in many places. In general, the following correlations are usually apparent:

- a. The greater the number of kettles the coarser the parent material.
- b. The absence of developed drainage channels, including gullies, implies coarse-grained and relatively clean parent materials.
- c. A deranged drainage pattern implies silty or clayey parent materials.
- d. Deflation hollows and sand smears imply relatively clean sand.
- e. Consistently steep slopes imply coarse-grained parent materials; consistently gentle slopes imply silty or clayey materials.

225. Soil profile characteristics. The surface soils are widely variable, depending primarily upon the nature of the parent material and topographic position. Parent materials change so abruptly in such short distances in some places that a distinctly mottled texture or pattern is displayed, especially in cultivated fields, as illustrated in fig. 25. In general, the A-horizon is less than 6 in. thick on the uplands; in the kettles and other lowlands it may be much thicker. The B-horizon ranges from 3 to 24 in. in thickness with the thinner sections occurring on the hill-tops. The B-horizon is commonly slightly more silty or clayey than the A-horizon. In general, there is a correlation between steepness of slope and soil type; SC, SM, and SP types tend to occur in areas having steep slopes, and CL and OH soils in more subdued areas. Clayey soils are also somewhat more common in climatic regions where the natural vegetation was grass.

226. The nature of the soils in the kettles and other depressions is in considerable measure dependent upon internal drainage. In kettles where such drainage is good, the soils are only slightly finer grained and more organic than those on the adjacent uplands. Soils in such locations are

commonly CH or MH, but they also may be SC or SM. The kettle identified by the marginal arrows labeled A in fig. 25 is an example of this type. On the other hand, if internal drainage is relatively poor, the kettle soils may be more or less continuously waterlogged, and may be highly organic as well as fine grained. Such types commonly contain OL or OH soil types. The kettle identified by the marginal arrows labeled B in fig. 25 is of this type. In relatively cold climates, such as that of northern Indiana, Michigan, Wisconsin, and Minnesota, kettles containing deep muck or peat (Pt) are common.

227. Trafficability and cross-country movement characteristics. Of the 17 sites in which the soils of the 6- to 12-in. layer were classified, 4 were in soil trafficability class C (CL), 12 in class D (SM, MH, OL, SM-SC, OH), and 1 in class E (Pt). Although there is no apparent correlation between topographic position and soil trafficability class, there is a relatively good correlation between organic content of soils and topographic position. Of the 8 highly organic soils tested (OL, OH, and Pt), all were in low positions, whereas of the 9 relatively inorganic soils tested (CL, SM, MH, and SM-SC), only 2 were in low positions. These two were classified as CL.

228. In general, topographically low areas having organic soils will be untrafficable, or at best marginal, regardless of season. During the wet season the highly organic soil areas become quagmires, with RCI's of 10 to 20. This is far too low to support any military vehicle. Sites to which the above generalizations apply can normally be identified on photographs by the combination of low topographic position and the dark photo tones. The latter is produced by a combination of dark soil color, high water content, and vegetation. The soils low in organic content have higher RCI's and are probably trafficable to vehicle categories 1, 2, and 3.

229. In general, the excellent internal drainage of the soils on topographically high sites ensures that soil moisture content remain comparatively low, regardless of season. The RCI's are in excess of 125 during the wet season, except that one SM soil had an RCI as low as 25. Where SM soils have a relatively high proportion of fines, the soils even on high positions may retain high moisture contents, resulting in severe loss of strength.

230. The steep slopes of kettle-kame moraines, which in many places approach 60%, are serious deterrents to movement. Although they can usually be avoided, the resulting paths are commonly very tortuous. Vegetation in intensively cultivated areas is rarely a deterrent, but in wooded areas the combination of steep slopes and trees may seriously inhibit movement. On slopes the fine-grained soils will be slippery.

Drumlin fields

231. Drumlin fields occur in widely scattered areas throughout glaciated regions. In North America, the chief areas are in New England, New York, Ontario, Michigan, and Wisconsin.

232. Regional drainage. The gross drainage pattern is generally of the deranged type, but in some places there is a marked tendency for scour channels to occur roughly parallel to the long axis of the drumlins. Dendritic patterns are occasionally present in some places. Low-order drainage patterns are widely variable; in the interdrumlin areas they are ditched or tiled in many places; on the drumlins they tend to be radial.

233. Topography. Drumlin fields exhibit a rolling cross-sectional shape. A drumlin field is composed essentially of groups of smoothly rounded elongate hills (the drumlins) superimposed on a flat or undulating surface. Drumlins are drop-shaped, streamlined forms, and in any given area the steep end of the form is consistently oriented in one direction, and the long axes of the forms are approximately parallel. In fig. 26, note that the steep ends of the drumlins (indicated by marginal arrows A) point toward the upper left corner of the photo. Drumlins range in height from 10 to about 100 ft, and in length from a few tens of yards to 1000 yd or more. Slopes rarely exceed 25%, and most are considerably less.

234. Local erosion. The flanks of most of the larger drumlins are scarred by subparallel C-type gullies. Evidence of sheet erosion may be subdued; it is normally indicated by slightly lighter photo tones on the sides of the drumlins than on either the top or bottom.

235. Natural vegetation. The natural vegetation of drumlins consisted chiefly of dense forests. Drumlin fields are, however, generally so intensively cultivated that little or no trace of the original vegetation remains.

236. Land use. Field patterns are generally rectangular, but shape

and orientation may be modified by topographic and drainage influences. For example, as illustrated by the drumlin in the upper half of fig. 26, the steep side slopes of the drumlins are commonly not worked, but are instead used as pasture or wood lots. Crops are generally diversified, resulting in widely variable tones and textures, as illustrated in fig. 26.

237. Construction practices. Road networks are normally rectangular, but there is a marked tendency for the pattern to be crudely aligned with the long axes of the drumlins. This tendency is most clearly seen on photomosaics or on very small-scale photographs. The side slopes of road cuts are normally cut back to relatively gentle slopes. In rural areas clusters of farm buildings are common. Perhaps the most striking cultural modification in drumlin fields consists of measures taken to improve drainage. These may be in the form of drainage ditches, as illustrated by the example marked with the marginal arrows B in fig. 26, or extensive tilling, or both. In some places, the entire drainage pattern has been converted to ditched courses, resulting in the remarkable combination of a basically deranged type laid out in mathematically straight lines.

238. Parent materials. The parent material of drumlins is invariably fine-grained plastic material, although it may be coated in some places with thin deposits of coarser-grained material. Some drumlins contain rock cores at shallow depths; such cores are occasionally exposed where the thin surficial clays have been breached by erosion. Drumlin fields tend to be associated with areas of shale and limestone bedrock. The parent material of the surface on which the drumlins are emplaced (i.e. the interdrumlin surface) is commonly a heterogeneous mixture of clay and silt with but minor admixtures of coarse-grained material.

239. Soil profile characteristics. The soil profiles on drumlins are normally relatively thin; the A-horizon rarely reaches 18 in. in thickness, and the B-horizon is widely variable but rarely exceeds 30 in. The chief soil type in the 6- to 12-in. layer on the drumlins is CL, but some SM soils occur, almost entirely confined to those areas where the drumlins are covered with a thin surficial deposit of silty or clayey sand.

240. Soils in the interdrumlin areas are normally plastic silts and clays with highly variable organic contents. Types include CH, SM, and MH, with Pt soils occurring in a few very poorly drained areas. These lowland

soils are relatively impermeable, and therefore retain high moisture contents for long periods of time.

241. Trafficability and cross-country movement characteristics.

Drumlin fields had soils falling into soil trafficability classes B, C, D, and E; those of the drumlins themselves (high topographic position) were chiefly C (CL) and D (SM), while those of the interdrumlin areas were mostly B (CH), D (MH), and E (Pt). The data are too few to allow firm generalizations to be made. All the soil types except the peat soils possessed sufficient RCI values to be trafficable for category 7 vehicles. The peat soils were trafficable only to vehicle categories less than 5. On the basis of soil type alone, it is probable that the coarse-grained soils on the uplands (i.e. the drumlins) are relatively strong, regardless of season, because of the opportunity for drainage, but that the fine-grained soils are exceedingly slippery when wet. The slipperiness factor, coupled with the relatively steep slopes, will probably result in considerable inhibition to wheeled vehicle movement. The soils of the topographic lows (i.e. the interdrumlin areas) are more variable; however, the generally poor drainage, both internally and externally, results in high soil moisture contents during the wet season, with resulting poor trafficability conditions. Areas of soils in trafficability classes D and E will probably be completely untrafficable during the wet season, and may be only moderately trafficable during the dry season.

Eskers and kames

242. Eskers and kames occur throughout areas that have been subjected to glaciation, but they are most common in Maine, Michigan, central Canada, and parts of northern Europe.

243. Regional drainage. Eskers and kames are normally too restricted in area to develop gross drainage patterns. The presence of eskers and kames may, however, interrupt other patterns, producing a special variety of deranged patterns. In esker fields (i.e. in places where several eskers occur close together) the trunk streams generally flow roughly parallel to the esker ridges, thus producing a crudely parallel drainage pattern. Low-order drainage is generally a relatively weakly developed parallel pattern if the sides of eskers are drained, and roughly radial if the kames are drained.

244. Topography. There is no clear line of demarcation between eskers and kames. In general, eskers are sinuous ridges displaying a crested cross section, as illustrated by the ridges dividing the lakes in the upper half of fig. 27, while kames are conical hills displaying the same basic surface expression. However, eskers may occur in groups or fields, in which case there is normally lineation of the landscape parallel to the trend of the ridges. Further, eskers frequently "degenerate" into lines of isolated hills or kame fields; an example is illustrated by the esker identified by the marginal arrow A in fig. 27. However, in most instances kames occur apparently at random on other forms of surfaces. In such instances they are usually but not invariably accompanied by kettles (for discussion of which see paragraph 217 on kettle-kame moraines). Kames and eskers are rarely more than 100 ft high, but may reach 150 ft in a few places. Slopes usually reach about 60%.

245. Local erosion. Gullies are rare; when present, they are V type with steep gradients. Deflation hollows may develop where the soil is sandy and the protective vegetation removed.

246. Natural vegetation. Prior to cultural practices implemented by man, eskers and kames were forested in humid regions; in subhumid and semi-arid regions they tended to be grass-covered in response to the excellent internal drainage which tends to produce soil aridity even in regions of considerable rainfall.

247. Land use. Eskers and kames are generally uncultivated. The granular soils and excellent internal drainage, plus the typically steep slopes, combine to reduce their agricultural utility. As a result, kames and eskers are commonly used only as pasture or wood lots. In glaciated areas, a streak composed of dark tones and botryoidal texture running across cultivation patterns is very often the photo expression of an esker covered with trees. Scattered circular or elliptical areas of similar tone and texture are usually kames.

248. Construction practices. Rectangular field patterns often terminate at the bases of eskers and kames. Primary roads are independent of eskers and kames since the granular material is so easily excavated that cutting through them is easy. Such cuts are smoothly edged, and have slopes of approximately 60%, slightly less than the angle of repose of

dry sand. In some places secondary roads may follow the crest of esker ridges, as illustrated in fig. 27, especially if the soils of the surrounding regions have poor bearing capacity or are highly frost susceptible. Gravel and sand pits are so prevalent in many places that they constitute a primary recognition feature.

249. Parent materials. The parent materials of eskers and kames consist chiefly of crudely stratified clean sand, gravel, and mixtures of sand and gravel. A few silt lenses occur in some places.

250. Soil profile characteristics. Soil profiles are in general very thin, rarely exceeding 12 to 14 in. Surface soils generally are of SP, SM, or SP-SM type, with little change throughout the weathered zone. On side slopes, SM soils (silty sands) are perhaps more common than other types. The sands and gravels composing the parent materials are commonly light in color; this, in company with the general lack of soil moisture as a result of the excellent internal drainage, results in very light photo tones when bare or thinly vegetated esker and kame surface soils are photographed.

251. Trafficability and cross-country movement characteristics. The single esker soil for which data are available fell into soil trafficability class D (SP-SM). The RCI was in excess of 300 regardless of season, and the soil is thus highly trafficable. This is generally true of all esker and kame soils; however, level areas between eskers and kames that may be subjected to seasonal water tables within 2 ft of the surface will become untrafficable except for category 1 and 2 vehicles. Where vegetation cover is thin or absent the cohesionless sandy soils may provide such poor traction that side slopes cannot be climbed even by tracked vehicles. In such places the presence of trees may impose an additional severe handicap by seriously limiting maneuverability.

Landscapes in Fluvial Materials

Alluvial fans and aprons

252. Alluvial fans and aprons develop in places where streams, usually but not necessarily intermittent, discharge from a topographic high into a topographic low and, in the process, sharply decrease in gradient.

They form to some extent in every climatic regime, but they are most prevalent and best developed in deserts. There is no clear distinction between fans and aprons; aprons are essentially coalesced fans.

253. Regional drainage. The gross drainage patterns of alluvial fans are chiefly fan-type distributaries, with the individual channels fading out at or near the base of the fan, as illustrated in the upper half of fig. 28. However, the slight shift in erosional regime may result in the development of radial drainage patterns as illustrated by the area indicated by the marginal arrows labeled A in fig. 28. The gross drainage patterns of alluvial aprons are generally combinations of types, with radial patterns near the bordering upland, changing to parallel near the base of the apron, as illustrated in the lower half of fig. 28. The drainageways commonly terminate in a large trunk drainageway trending at a sharp angle (often nearly 90 degrees) to the apron channels, or to a playa. Low-order drainage patterns on both fans and aprons are generally dendritic but distinctly elongate, so that they are a form midway between dendritic and parallel, as shown in fig. 28. Virtually all channels on fans and aprons are of the braided type, as also shown in fig. 28.

254. Topography. Alluvial fans and aprons generally exhibit blocky cross-sectional shapes. The topographic highs (i.e. the areas between the drainageways) are generally more or less flat-topped or gently convex, as illustrated in the upper half of fig. 28. The regional slope of the surface is away from some form of topographic high toward a valley or basin. The regional slope rarely exceeds 12%, and is usually less than 9%. Slopes are generally steeper on the edge of the fan or apron toward the topographic high from which the parent materials were derived, so that the regional slope forms a surface gently concave upward. Most aprons have fan-like elements forming the upper edge (i.e. that portion closest to the topographic high) of the apron surface, as shown by the area indicated by the marginal arrows labeled B in fig. 28.

255. Local erosion. Fans and aprons can be subject to extreme gully erosion. In arid regions, gullies may be nearly saucer-shaped or very gently V-shaped near their head; farther downslope they normally become steep-sided (in many instances vertical-sided) and flat-bottomed (i.e. F type). However, in arid climates gullies cannot be used as an indicator

of soil or parent material type. On the other hand, in humid regions the gullies that form in alluvial fans are indicators of soil and parent material type. Because the fan material in such instances may be widely variable from region to region, the gullies tend to be widely variable in shape as well.

256. Wind erosion is relatively common on fans and aprons in arid climates. It does not normally produce deflation hollows, however. Instead, it removes the fines and leaves the surface "armored" with a layer of blackened pebbles, the so-called "desert pavement" (see medium gray areas in upper right corner of fig. 28). This process results in a curious inversion of the tonal patterns found in humid regions. The uplands in such instances photograph dark gray; this fades off rather sharply into the washes, which normally photograph in very light tones. However, not all fan and apron surfaces are subject to this process, so that this pattern may not be present in all (or even most) examples.

257. Natural vegetation. Vegetation on alluvial fans and aprons is responsive to the degree of aridity. In North America, where at least some rain falls every year, the drainage lines are marked by lines of vegetation. On airphotos these show as lines of dark-toned dots which tend to stand out sharply against the generally light-toned washes. The precise alignment of the denser and larger vegetation growths is often one of the most striking features of photos of fans and aprons. As the amount of rainfall for a region increases, shrubs begin to cover the interfluves, and this pattern becomes less distinct. In humid regions, alluvial fans are normally forested.

258. Land use. In desert climates alluvial fans and aprons are rarely used for purposes other than livestock grazing. However, in some places the fans or aprons may be irrigated and cultivated. The presence of cultivation implies a primarily silty parent material. Field patterns are generally rectangular and independent of drainage or topography.

259. Construction practices. Primary roads are independent of drainage and topography. However, they are frequently protected by relatively elaborate dikes and other flood-control works where they cross washes. Secondary roads commonly avoid crossing washes wherever possible. Despite the usual presence of sand and gravel sizes in fan and apron parent materials, these landscapes are rarely used as sources of aggregate for

industrial or construction purposes because of generally low population density.

260. Parent material. The parent materials of alluvial fans and aprons are widely variable in both grain size and mineralogy, depending on the source materials in the uplands. The materials are normally crudely stratified. The following generalizations may be made, although many notable exceptions occur:

- a. The coarser the material the steeper the regional slope.
- b. The finest materials are farthest from the highland front. In general, this implies that the parent materials at the base of any given fan or apron will be finer grained than those near its apex or upper edge.
- c. Source areas (i.e. highlands) of coarse-grained igneous rock produce sand-silt mixtures.
- d. Source areas of fine-grained igneous rock produce angular fragments of gravel or cobble size and fine sand-silt mixtures.
- e. Source areas of coarse-grained sedimentary rocks produce subrounded to angular gravels and sand-silt mixtures.
- f. Areas of fine-grained sedimentary rocks (i.e. shales) produce fine-grained materials. Fans and aprons containing this material can sometimes be identified by the presence of mudflows; lobate, light-toned areas contrasting with the generally darker tones of the body of the fan.

261. Soil profile characteristics. Soil profiles are often poorly developed or absent on fans and aprons in arid regions. All samples of soils tested for this study were taken in California; it is therefore impossible to develop regional generalizations. Further, almost without exception, the soils tested were located on the interfluvies; accordingly, the soils in the washes, which cover a substantial fraction of the fan or apron area, are represented by only two samples. In the region of study, coarse-grained (SC, SM-SC, and SM) and fine-grained soils (CH, CL, and ML) occur with about equal frequency in the 6- to 12-in. layer. Most of the latter, as might be expected, were found in fans and aprons derived from shale and other fine-grained sedimentary rocks.

262. In some places, much of the surface is covered with desert pavement. This normally consists of a single layer of closely fitted pebbles overlying silty or sandy materials of great depth.

263. Trafficability and cross-country movement characteristics. All sites except one were located in low topographic positions. The soils tested fell into soil trafficability classes B (CH), C (SC and CL), and D (SM-SC, SM, and ML). These soils were tested under unusually wet conditions and the following discussion, therefore, is believed to represent the worst possible trafficability conditions that would ever be encountered on these surfaces.

264. The class B soil (CH) exhibited an RCI of 85, indicating that these soils would be untrafficable for category 7 vehicles and marginal for category 6.

265. Class C soils (SC and CL) were highly variable. The SC soil exhibited an RCI of 66, and would be untrafficable for category 5-7 vehicles, and marginal for category 4. The CL soils were highly variable in strength range. The RCI's ranged from a remarkable low of 14 to a high of 223. In general, the low values were obtained in undrained or irrigated areas. Thus, at least some low areas would be completely untrafficable to all vehicles, while at least some high sites would be trafficable for all vehicles.

266. Class D soils (SM-SC, SM, and ML) were found, oddly enough, to be the most trafficable soils of the fans and aprons. The poorest of this group were the SM-SC soils, which exhibited RCI's of 94 to 215; these soils should be untrafficable only for category 7 vehicles at worst, and in most places would be trafficable for all vehicles. The ML soils exhibited RCI's of 178 to 256, indicating excellent trafficability for all vehicles. The SM soils exhibited RCI's of from 231 to more than 300, indicating excellent trafficability conditions.

267. Trafficability conditions on all alluvial fan and apron soils would be excellent when the soil moisture contents are low, although almost all such areas are very dusty in this condition. The many steep-sided gullies that occur so often on fans and aprons constitute serious handicaps to cross-country movement, especially when the direction of movement is across the "grain" of the drainage pattern. Careful examination is normally required to find a route which any vehicle can negotiate without engineer assistance. Vegetation is rarely an inhibiting factor.

268. The data reveal that the irrigated test areas gave RCI readings

greater than those RCI readings reported for nonirrigated areas. It is to be noted, however, that during and for about four days after an irrigation cycle, the RCI's will be substantially lower than those recorded. It is believed that CL and ML soils will be trafficable only to vehicle categories 1 and 2 during an irrigation cycle.

Outwash surfaces

269. Outwash surfaces are formed by the deposition of materials from perennial (or nearly perennial) streams. The materials forming the surface may be derived from mountains or some other type of highland, or from glaciers. There is obviously no clear distinction between alluvial aprons and outwash plains; outwash plains may in fact be regarded as a variety of alluvial apron having a very low regional dip, as opposed to the relatively steep regional inclination of alluvial aprons. In this report, only outwash surfaces composed of materials derived from continental glaciers are discussed and illustrated. However, such features as the High Plains region of the North American Great Plains are also outwash plains, differing only in that the materials of which they are composed were derived from the Rocky Mountains by stream erosion.

270. Regional drainage. The gross drainage pattern is roughly parallel. The channels are usually very widely spaced. Note that in the entire area illustrated in fig. 29 there are no active scour channels. Drainage is almost entirely internal in such areas. Areas of kettle-hole drainage are common; in many places the kettles are distinguished by an almost complete lack of drainage channels leading to them. Low-order drainage patterns are generally dendritic, or centripetal around large basins.

271. Topography. Outwash surfaces almost invariably exhibit undulating cross-sectional shapes. Basins are common in some places, absent or rare in others. Relief is very low, rarely exceeding a few feet. It is usually too low to be detected stereoscopically. In many instances the basins are identifiable only because the soils within them show darker tones than the surrounding uplands, as illustrated in fig. 29. The basins are normally irregular in shape and relatively small, rarely exceeding 50 yd in diameter. In some places basins with steep side slopes may occur individually or in chains forming channels.

272. Local erosion. Relief is generally too subdued to permit gully formation except in a few places along major streams. Where present, gullies are V type with very steep gradients. Deflation hollows may develop where vegetation has been removed from sandy soils. Fixed dunes of very low relief are found in a few places.

273. Natural vegetation. Vegetation is largely dependent upon climatic regime. However, most glacial outwash plains in the Great Lakes region of North America were forested. The trees were either hardwoods or conifers, depending primarily upon climate. Many outwash plains are now under cultivation, so that little trace remains of the original vegetation; however, some are again forested after being once logged. In such cases, the tree cover may completely mask such surface features as the small basins.

274. Land use. In cultivated areas, field patterns are rectangular and almost completely independent of topography, as illustrated in fig. 29. Crops are normally very diversified, resulting in markedly different photo tones and textures in adjacent fields. Wood lots are generally few, small, and scattered. Relatively large areas of forest in an otherwise cultivated outwash plain commonly indicate relatively sandy soils.

275. Construction practices. Roads are in rectangular pattern and independent of topography. Gravel and sand pits occur in some localities. In rural areas clusters of farm buildings are common.

276. Parent materials. Parent materials are relatively clean, crudely stratified sands and gravels, with occasional silt lenses of limited areal extent. Clay lenses, although not unknown, are rare. Local variations in grain size are to be expected, and can in some instances be identified on airphotos. In general, the following generalizations obtain, but exceptions are common.

- a. Gullies are more prevalent in predominantly gravel parent materials than in sand parent materials.
- b. Deflation hollows generally indicate relatively clean sand as a parent material.
- c. The larger the number of basins the coarser the parent material.

277. Soil profile characteristics. Surface soils are widely variable, depending primarily upon the nature of the parent material and the

topographic position. The most striking soil differences occur between the topographic highs and lows, even though the relief may be only a few inches. The lows may be subsidence hollows (i.e. the basins that characterize most outwash surfaces), or they may be the filled channels of abandoned glacial (probably) streams. Both basins and channels photograph in dark tones because the organic content and soil moisture content are higher than those in the adjacent areas. The basins result in a speckled pattern on photos, while the channels may produce a streaked pattern. Both are illustrated in fig. 29.

278. In general, the A-horizon on the uplands is of CL, SC, or SP-SM type, and is normally less than 9 in. thick. In the hollows and filled channels it may be very much thicker, and frequently consists of peat or muck (Pt), or of organic sands and silts, or OH types. The B-horizon is normally from 10 to 60 in. thick, and is commonly somewhat more plastic than the A-horizon. It is frequently mottled red and brown. These soils usually retain high moisture contents for long periods of time.

279. Trafficability and cross-country movement characteristics.

Soils on high topographic positions fell into soil trafficability classes C (SC and CL) and D (SP-SM). Both classes exhibited RCI's in excess of 100 in the 6- to 12-in. layer in the wet season. The surface soils that are sandy are usually loose when dry, but the 6- to 12-in. layer remains firm. These areas are trafficable all year round but loose dry sands will result in some traction failure for wheeled vehicles, especially when operated at high tire pressures.

280. Soils in low positions (the basins and channels) fell into soil trafficability classes D (SM, ML, and OH) and E (Pt). The class D soils exhibited RCI's from 91 to 174 during the wet season. Hollows and channels filled with class D soils are trafficable all year to all vehicle categories except category 7 which will experience difficulty during the wet season. However, the class E soils (Pt) exhibited an RCI of only 20 during the dry season, and 11 during the wet season. These soils may be untrafficable for all vehicle categories except 1 in any season.

281. Slopes are rarely if ever steep enough to constitute an inhibition to cross-country movement. The vegetation in areas of forest may, however, be a considerable handicap, especially if the trees are large.

Floodplains

282. Floodplains are surfaces which are adjacent to streams and which are flooded by the stream more or less regularly. No restrictions on size are implied; in this report the floodplain may consist only of bars exposed in the channel at low water, as well as the vast expanses of plain flooded by such streams as the Mississippi. The stream with which the plain is associated need not be perennial; in this report the alluvial fill in the valleys of such streams is regarded as floodplain if the stream normally floods it from time to time. This general category provides no clear visualization of the complexly associated environments of many floodplains. For this reason, the descriptions of the various factors have been subdivided into several of the more important (i.e. widespread) environments. Those specifically described are: ridge and swale topography, natural levees, backswamps, abandoned courses, and high-level floodplains. It must, however, be emphasized that not all of these environments occur in every floodplain. Many floodplains are composed of only one or two.

283. Regional drainage.

- a. Ridge and swale. The gross drainage pattern is basically dendritic, but is commonly very distorted; it may form a special type of deranged pattern. The channels may be broadly meandering, and in some cases there will be small-scale meanders superimposed on much larger loops. Low-order drainage is generally collinear, with the drainage ways following arcuate swales. Some swales may not exhibit developed scour channels, as illustrated in photo a of fig. 30. Some swales may be basins, which form shallow, elongate lakes or ponds after rain.
- b. Natural levee. These landscapes are generally too restricted in area to develop gross drainage patterns. Low-order drainage is usually the parallel type, with the channels draining the gentle reverse slope (i.e. away from the river) of the ridge, and thus oriented roughly at right angles to the trend of the ridge and the river. Such drainage is commonly straightened and deepened by man to improve drainage, as illustrated in photo b of fig. 30. Natural channels may be widely spaced, or they may be entirely absent.
- c. Backswamp. The gross drainage pattern is normally dendritic, but also may exhibit some of the features of the reticulate type (i.e. channels bifurcate and rejoin in complex patterns very similar to those which occur on deltaic plains, as illustrated by photo a, fig. 31) and

deranged types. There may be no obvious trend to the drainage as a whole. Channels are commonly contorted. Lakes with exceedingly irregular outlines are not unusual, especially on the floodplains of large streams. Low-order channels are basically dendritic, but they may be entirely concealed in places where the swamps are forest-covered. Where cultivated, the patterns are usually either (or both) ditched or tiled.

- d. Abandoned course. These landscapes are generally too restricted in area to develop gross drainage patterns. Low-order drainage is normally parallel to, and remains within, the abandoned course. Channels are commonly meandering. Lakes of the so-called "oxbow" type usually fill or partially fill the abandoned course.
- e. High-level floodplain. Both gross and low-order drainage patterns are predominantly dendritic, but the landscape may exhibit traces of patterns "inherited" from earlier times; thus, it may be crudely collinear or parallel.

284. Topography.

- a. Ridge and swale. The cross-sectional shape is undulating. The ridges and swales are concentric and usually arcuate. Local relief is rarely more than a few feet, and may be so subdued as to be undetectable by stereoscopic examination. This type of topography is sometimes called "point bar"; it forms on the inside of meander loops. The concentric structure is commonly truncated by the existing channel. The middle portion of photo a in fig. 30 illustrates this condition. It is almost invariably present in the floodplains of meandering streams, but may be absent in those of nonmeandering streams.
- b. Natural levee. The cross-sectional shape is generally undulating or blocky. The levees consist of asymmetric ridges of very low relief parallel to a stream channel. The steep slope (frequently an abrupt "cut bank") faces the water, and the very gentle reverse slope faces away from the stream, as illustrated in photograph b, fig. 30, and photo b, fig. 31. Relief may be from a few inches to as much as 15 or 20 ft, though these extremes are rare. The ridges range in width from a few yards to a mile or more. Changes in river courses may leave natural levees abandoned and far from the present course. Old levees may be intercepted or truncated by newer ones. They are most common in the floodplains of meandering streams, but they may occur to some extent along channels of other types.
- c. Backswamp. The cross-sectional shape is undulating, and is commonly very nearly plane; relief is normally only a few inches or at most a few feet. Areas of backswamp are extremely variable in size even in the same floodplain; they may range from a few hundred square yards to several

square miles. They are normally bounded on at least one side, and frequently on all, by natural levees. To this extent they are very shallow closed basins, although usually there is at least one drainage exit.

- d. Abandoned course. This surface normally consists of a relatively narrow band or belt bounded by either (or both) natural levees or ridge and swale topography. It may range in width from a few feet to a mile or more, depending upon the size of the stream that once flowed therein. The cross-sectional shape is generally undulating and of very low relief. It may in some places contain closed basins.
- e. High-level floodplain. This surface is normally flooded only during extremely high water stages. The cross-sectional shape is generally undulating or blocky. Relief is normally only a few feet or at most a few tens of feet. This surface commonly occurs as discontinuous segments along the edges of the floodplain, but it may also occur as outliers within the low-level floodplain. Sizes are variable, ranging from a few hundred square yards to several square miles.

285. Local erosion.

- a. Ridge and swale. This surface rarely if ever exhibits gullies. Where the surface is newly formed (i.e. along active channels), deflation hollows may develop.
- b. Natural levee. Most natural levees exhibit little or no gullying, chiefly because local relief is inadequate for gully development. However, where such levees have been abandoned, the steep face of the ridge may develop gully systems. In general, these are V type with steep gradients. When floodwaters overtop the natural levees, they tend to scour the reverse slope; the marks resulting from this are generally indefinite, but there is normally a distinct impression of lineation at approximately right angles to the trend of the levee. The lineation is evidenced by alternating, poorly defined streaks of light and dark photo tones produced by minor differences in vegetation cover and, probably, soil type.
- c. Backswamp. These surfaces rarely exhibit evidence of local erosion. However, in some instances where local relief for some reason exceeds a few feet, gullies of the C type may develop.
- d. Abandoned course. These surfaces rarely exhibit evidences of local erosion of any type.
- e. High-level floodplain. Gullies are relatively common on these surfaces, especially near the margins. Because the parent materials and soils of such features are quite variable, the gully forms are also variable. Perhaps the most

common is the V type with steep gradients, but virtually any type may occur.

286. Natural vegetation. Floodplain vegetation in general is dependent upon climatic regime, but to a lesser extent than that of most other landscapes. Water is normally adequate for abundant plant growth, even though rainfall may be very low. Nevertheless, there are significant variations between tropic, desert, temperate, and arctic climatic types. The following descriptions apply only to humid-temperate climates, such as those of the eastern United States.

- a. Ridge and swale. When ridges and swales are newly formed, vegetation may be absent. These surfaces are then colonized by small herbs and grasses, then shrubs, and finally by dense forest. However, the swales may remain waterlogged, and in some instances will support only dense growths of marsh grass or reeds. The contrast between the dark-toned botryoidal texture of the trees on the ridges and the smooth, generally light-toned grasses of the swales is often striking. Where trees cover the entire surface, as they frequently do, they may completely obscure the typical topography, including even the drainage pattern.
- b. Natural levee. These surfaces were normally forested, as illustrated in upper right corner of photo a, fig. 30. When such an area is forest-covered, the trees may mask the typical streaked appearances.
- c. Backswamp. These surfaces were normally forested, although in some places extensive areas of marsh grass and reeds occur, especially in and near the lakes, very similar to those occurring in deltaic plains, as illustrated in photo a, fig. 31.
- d. Abandoned course. These surfaces were normally forested. However, near oxbow lakes, especially at their ends, extensive areas of grass or reeds may occur.
- e. High-level floodplain. These surfaces were normally densely forested.

287. Land use and construction practices.

- a. Ridge and swale. Newly formed ridge and swale areas, and those in process of forming (i.e. active point bars) are rarely cultivated. Old surfaces of this type are commonly cultivated. In such places, the normally sharp distinction between drainage conditions and soil types from ridge to swale commonly results in a field pattern consisting of elongate rectangles oriented parallel to the trend of the topography. See photo a, fig. 30, for an example. Many

exceptions to this generalization occur. The difference in soil conditions encourages different crops on each; this practice may accentuate the normal difference in photo tone between the ridge and swales, and produce a strikingly streaked pattern. In construction practices, roads tend to follow ridges. Sand and gravel pits are common in localities where the parent materials are relatively clean sands or gravels.

- b. Natural levee. This landscape is generally the most thoroughly cultivated of the floodplain environments. The soils are usually well drained, encouraging diversified agriculture. Field patterns are often rectangular, and tend to be aligned parallel to the typical streaked pattern, as illustrated in photo b, fig. 30, and photo b, fig. 31. Roads parallel the trend of the ridge where these features are fairly large (e.g. along major drainageways), as illustrated in photos a and b of fig. 31. Natural levees are often used as the bases for artificial levee systems. Borrow pits for construction of road, railroad, and levee embankments are common.
- c. Backswamp. The soils of backswamps are generally poorly drained and difficult to work. As a result, this environment is commonly left in timber; where cleared, it is frequently used for grazing. However, in many places backswamps have been either naturally or artificially drained, in which case the field patterns are rectangular and tend to be independent of topography. Roads and railroads avoid backswamps where possible. Where it is necessary to cross backswamps, both cut across without regard to topography, although they are aligned to avoid the lakes or the marsh areas. Where backswamps are used for agriculture, ditching is usually required.
- d. Abandoned course. The soils of abandoned courses are generally poorly drained and difficult to work. As a result, this environment is left in timber or used for grazing. Roads and railroads avoid abandoned courses where possible. Where crossings are unavoidable, they are generally aligned at right angles to the trend of the abandoned course.
- e. High-level floodplain. These surfaces are commonly cultivated. The field patterns tend to be rectangular and independent of topography. Areas of poorly drained soils (i.e. usually old backswamp areas) are in timber. Roads are generally laid out in rectangular pattern independent of topography, although they tend to avoid poorly drained areas.

288. Parent materials.

- a. Ridge and swale. The parent materials of ridge and swale surfaces are generally sandy or gravelly on the ridges, with finer-grained materials forming the swales. In some places this distinction becomes extreme, with sand

composing the ridges, and clays and silty clays composing the swales. There is considerable variation from region to region, or even along different segments of the same floodplain. In some cases (e.g. when the parent stream has a steep gradient and swift current), the ridges may be nearly pure gravel; in others (e.g. where the parent stream has a gentle gradient and slow current), the ridges may be composed of silty sand.

- b. Natural levee. This landscape is generally composed of sand and silty sand, although there is considerable variation in texture from place to place.
- c. Backswamp. The parent materials of backswamps are chiefly silt, clay, and mixtures of both.
- d. Abandoned course. The parent materials of this landscape are chiefly clay and silty clay.
- e. High-level floodplain. These may be composed of any or all parent materials found in the low-level floodplain, because the high-level floodplain is chiefly a remnant of a low-level floodplain formed at an earlier time. High-level floodplains are thus composed of more deeply weathered and dissected natural levee, ridge and swale, backswamp, and abandoned course deposits.

289. Soil profile characteristics.

- a. Ridge and swale. The surface soils of this landscape are normally relatively thin, and are chiefly relatively impermeable silty sands, clay silts, and silty clays. Soils tend to be slightly coarser on the ridges, slightly finer and more organic in the swales. Highly organic silts and clays occur in relatively infrequent, exceptionally poorly drained swales.
- b. Natural levee. The surface soils of this landscape are generally thin, and variable depending upon topographic position. They are generally coarser grained near the crest of the ridge (i.e. close to the river channel), and relatively finer near the base. They are chiefly sandy silt and silty clay, although other types occur.
- c. Backswamp. The surface soils are generally thin and relatively poorly developed. They are dense, highly organic, impermeable clays and silty clays.
- d. Abandoned course. Surface soils in these landscapes are variable depending upon many complexly interrelated factors. In general, however, they are highly organic, impermeable clays and silty clays.
- e. High-level floodplain. Because this landscape is essentially an older edition of the low-level plain, the surface soil profiles are generally considerably thicker than those

of the low-level plain, but they are of the same general types, depending upon the types of deposits forming the surface.

290. Soil profiles as tested. Unfortunately, the soil tests made for this report were not initially classified as to specific environment within the floodplains themselves. Accordingly, only very general statements can be made on the basis of the testing program. In general, high topographic positions have organic soils of types OL and OH in thicknesses up to about 6 in., while in topographic lows these same types occur in thicknesses up to 18 in. Highly plastic soils of type CH occur in many localities. All soils tested were fine grained to a depth of more than 18 in.

291. Trafficability and cross-country movement characteristics. Of the 37 sites in which trafficability determinations were made, 12 were on topographically high sites and 25 on low sites. There appears to be no correlation between soil type and topographic position. The soils fell into soil trafficability classes B (CH), C (CL), and D (ML, CL-ML, MH, OL, and OH), with the majority (about 95%) in classes C and D. The high sites were more trafficable than the low sites. The RCI for high sites was in the majority of cases in excess of 100, ranging from 84 to 166. In the low sites, the class B soils exhibited RCI's in the range of 85 to 164 during the wet season. These soils would probably be trafficable for all vehicle categories during the dry season, but would be difficult or impossible for category 6 and 7 vehicles during the wet season. Slipperiness and stickiness, however, would render going difficult. During the wet season the class C soils exhibited RCI's in the range of 61 to 153 for the high sites and 52 to 94 for the low sites. The soils of the high sites apparently are very similar to class B soils in trafficability characteristics but the low sites will be trafficable to vehicles in categories less than 4.

292. The class D soils, however, are somewhat less satisfactory for trafficability purposes. The RCI during the wet season ranged from 95 to 166 for the high sites and 41 to 131 for the low sites. High site soils would be trafficable during the wet season for vehicle categories 1 through 6, and the low sites would be trafficable to vehicle categories 1 and 2. Even during the dry season at least some of these soils will

probably be untrafficable for category 6 and 7 vehicles because poor drainage keeps these soils wetter for longer periods.

293. The complex associations of soil types in floodplains, coupled with the fact that nearly 49% of them (class D soils) would be untrafficable for all vehicles except categories 1 and 2 during the wet season, make it probable that cross-country movement of any appreciable distance through floodplains would be very difficult during this season. During the late dry season cross-country movement would be relatively easy. Vegetation would be a severe inhibition to movement in the wooded areas. Slopes would not normally be a problem, but many streams have relatively steep banks, and these might pose serious problems, especially when wet.

Deltaic surfaces

294. There is no clear line of distinction between a delta and a floodplain; the delta is in a sense only the floodplain extended into the terminal water body. However, because the deltaic surface is formed by the complex interaction of littoral, lacustrine, marine (if formed at sea-coasts), and fluvial processes, these features typical of floodplains are somewhat modified, and several features not normally found in floodplains may occur. The deltaic surface is typically a very gently undulating surface slightly above the level of the terminal water body. The surface normally consists of complex arrangements of natural levees, distributary channels, abandoned beach ridges, and swamps and marshes, but any one or several of these components may be absent in some places.

295. Deltaic surfaces of some type tend to form at the mouth of nearly every stream that discharges into lakes or seas. Some are destroyed by wave and current actions as rapidly as they are formed, but the remainder develop to a greater or lesser extent, depending upon complex factors of the environment. Three fundamental delta types are recognized--digitate, arcuate, and estuarine. There is no clear distinction between the forms; a very large number of intermediate forms occur. Deltas range in size from a few square yards to hundreds of square miles. For example, photo c of fig. 31 illustrates a small estuarine-type delta filling the end of a lake in Wisconsin; the entire delta is only about one-half mile long. On the other hand, photos a and b of fig. 31, at the same scale (1:20,000), illustrate only tiny portions of an enormous deltaic surface in Louisiana.

296. The gross drainage pattern of most deltas consists of a basic distributary (i.e. delta) system through which the delta-forming stream discharges. The channels of such distributaries may be of any type, depending on such factors as stream gradient, tidal range of the water body into which the stream discharges, and the transported materials. The major channels of the digitate type are usually relatively straight and simple, as illustrated in photo b of fig. 31. Those of arcuate deltas may be straight or meandering, and are commonly complexly interconnected, as illustrated in photo a of fig. 31. It should be emphasized that all delta types grade into each other, so that occasionally one portion of a delta may be typically digitate, another arcuate, and still another estuarine. Estuarine distributaries may be of almost any type; meandering, straight, and braided channels are all common. They may be somewhat reticulate, but confined between bounding valley walls. In places where the level of the terminal water body is nearly constant, the channels may be so obscured by vegetation that they are nearly unrecognizable, as illustrated in photo c of fig. 31.

297. Between the distributaries there are generally low-order drainage patterns that are similar in type to those found on floodplains. The most common environment is a variant of the backswamp (for description of which see section on floodplains).

298. Topography. The cross-sectional shape is chiefly undulating, with local relief rarely exceeding a few feet. Many aligned forms, such as ridge and swale surfaces, are common on deltas. On digitate deltas, such as the mouth of the Mississippi and many others, the natural levees extend into the terminal water body on both sides of the distributary channels, thus forming a variety of aligned surfaces. Natural levees on deltas are generally even more sharply defined than those on floodplains. They tend to be narrower, as illustrated in photos a and b of fig. 31. The swamps between the distributaries, illustrated in photos a and b of fig. 31, are the most common and most extensive delta surfaces; they are normally so gently undulating that relief cannot be detected with a stereoscope.

299. Local erosion. The relief of deltas is generally too low to permit gully erosion. Deltas, being normally well watered, are even less

subject to eolian erosion than are floodplains, although such erosion does sometimes occur in arid climates.

300. Natural vegetation. Delta vegetation is controlled by climatic regime to an extent similar to that in the case of floodplains. Being normally well watered, deltas even in semiarid areas are commonly forested. However, extensive areas of marsh occur, and vegetation may be very complex as a result of the complex mosaic of environmental types resulting from shifting balances of water salinity, drainage, soil types, etc.

301. Land use. Deltas are used in a multitude of different ways. They may be intensively cultivated, as are those of the Nile or Ganges, or they may be relatively untouched, as are those of the Yukon, Niger, and Amazon, or they may be combinations of both, such as the Mississippi. In the eastern United States, cultivated fields are generally rectangular and more or less independent of topography; other lands and people use field patterns of a bewildering variety of types.

302. Construction practices. Where deltas are cultivated, drainage works such as ditches and tiles are prevalent. Extensive drainage canals have been constructed in many places as public health measures. In arid regions, irrigation works are normally present. Where the delta-forming stream is large, the channel may be used as a harbor (as for example, New Orleans); in such instances river training works of various types are frequently present. Deltas which are extensively cultivated are commonly the sites of large cities or towns. Examples include Cairo, Calcutta, New Orleans, and Haiphong. Roads and railroads tend to follow natural levees across large deltas, although exceptions to this generalization are common, especially in highly industrialized areas. Artificial levees are very common on cultivated or densely populated areas.

303. Parent materials. As with floodplains, delta materials vary widely in type, depending on the nature of the depositing stream and to some extent on the nature of the terminal water body. Streams with steep gradients tend to form deltas composed of relatively coarse-grained materials, while streams with gentle gradients tend to deposit finer-grained materials. Thus, digitate deltas tend to be composed of fine-grained material. For example, the Mississippi delta is composed chiefly of grain sizes of less than 0.1 mm. The same general relations between

environments and parent materials occur for deltas as for floodplains.

304. Soil profile characteristics. Surface soil profiles are usually, but by no means invariably, quite thin. Deltas composed of coarse-grained materials (chiefly arcuate and estuarine types) may have complex associations of soils of types SW, SP, and SM. In some deltas formed by rivers of very steep gradients, even gravelly soils occur. Digitate deltas may have soils in the silt and clay ranges, such as MH, CL, and OH. However, even on such deltas, sandy soils (SM) are not uncommon, especially on the natural levees. Many exceptions to these generalizations occur.

305. Trafficability and cross-country movement characteristics. The soil tests of trafficability conditions in deltas were too few to permit generalizations. The results were, in fact, somewhat anomalous. The soils in an arcuate delta (north end of Great Salt Lake, Utah) fell into soil trafficability class D (SM and OL). The SM soil exhibited an RCI of 70 during the wet season, indicating that this soil would be untrafficable for vehicle categories 5, 6, and 7. On the other hand, this soil would probably be trafficable for all vehicles during the dry season, although vehicles in categories 6 and 7 would find going difficult. The OL soil exhibited an RCI of only 36; this soil would be trafficable only for category 1 vehicles and marginal for category 2 vehicles during the wet season. During the dry season this soil is probably trafficable only for category 1, 2, 3, and perhaps 4 vehicles.

306. The soils tested on a digitate delta (that of the Mississippi River), on the other hand, fell into soil trafficability classes A (SP) and C (CL). The class A soil, taken from a natural levee, exhibited a CI of 126 in the 0- to 6-in. layer during the wet season. This value, plus the texture of the soil, indicates that it would be easily trafficable at any time of the year for tracked vehicles but clean sand would present traction difficulties to conventional wheeled vehicles operating at high tire pressures. On the other hand, the class C soil, taken in a topographically low position, exhibited an RCI of 54, which suggests that this soil would be untrafficable when wet for all except (perhaps) category 1 and 2 vehicles.

307. Slopes will rarely be an obstacle to movement on deltas. However, the numerous stream channels would pose serious obstacles, even on comparatively small deltas, because the banks are commonly abrupt. Where

deltas are cultivated, the numerous drainage ditches or irrigation canals would add to the problem. Vegetation would seriously inhibit or even completely stop movement in many places where the deltas are not cultivated.

Terraces

308. Terraces are found along the valleys of most large and many small streams. In general they are the remnants of alluvial surfaces that formed at some time in the past at a higher level than the floodplain of the stream now flowing in the valley. There is no clear distinction between a terrace and a high-level floodplain. In this report, the landscape is a terrace if it is not inundated by floodwaters more or less regularly. The surface of a terrace may range from a few feet above the present floodplain to heights of 100 ft or more above it, and in area from a few hundred square yards to several square miles.

309. Regional drainage. Terraces are generally too restricted in area to develop gross drainage patterns. In many places they are devoid of all drainage channels, even low-order ones. Many exhibit variations of swallow-hole or kettle-hole drainage, but the basins are normally without a trace of scour channels leading to them, as illustrated in fig. 32. In places where upland streams debouch onto terrace surfaces, the channels are usually deflected along the valley walls, thus forming an anomalous pattern.

310. Topography. The cross-sectional shape is generally undulating. Small basins are common in many places, but a single terrace may exhibit basins in one part and none in another. Local relief is rarely more than a few feet. The basins are generally shallow, C-type depressions rarely more than 50 yd in diameter. However, in some places they are elongate, and in such instances they tend to be crudely aligned. Both types are illustrated in fig. 32. In many places a shallow depression may extend along the base of the bounding valley wall. Note the crudely developed example illustrated in fig. 32, trending parallel to the marginal arrows labeled A.

311. Local erosion. Terraces are normally devoid of gullies except at their valleyward edge. V-type gullies with steep gradients indicate coarse-grained materials, and F-type gullies with relatively slight gradients indicate silty materials. C-type gullies are relatively rare, though they do occur in some places. Where gullies debouch from the uplands onto

the terrace surface, small alluvial fans are normally built out onto the terrace. Wind erosion may produce deflation hollows and sand smears on terraces in places where vegetation has been removed from cohesionless sandy or silty soils.

312. Natural vegetation. In humid-temperate climates these surfaces were forested; in semiarid climates they were chiefly grass-covered.

313. Land use. Terraces are generally cultivated or used as grazing land. Field patterns are generally rectangular and independent of topography on the terrace surface, but they commonly terminate at odd angles at the terrace edge, as illustrated at the lower edge of fig. 32, or at the valley wall. The sometimes relatively steep slopes of both terrace edges and valley walls are left covered with trees, so that the terrace surface is in some places nearly enclosed by a belt of forest. As illustrated in fig. 32, there are many exceptions to this arrangement.

314. Construction practices. Roads are independent of terrace topography, but their alignments are influenced by terrace edges, as illustrated at the lower edge of fig. 32. Terrace materials are exploited for construction purposes, road materials, or industrial uses; the presence of a gravel or sand pit, such as the one indicated by the marginal arrows labeled B in fig. 32, generally indicates relatively clean, coarse-grained parent materials. Terraces are frequently used as sites for airfields (see middle of fig. 32) and towns; the generally level surface, good drainage, and good foundation conditions are ideal for these purposes.

315. Parent materials. Parent materials are widely variable, as befits an old floodplain surface. However, certain regional generalizations are possible. In the Great Lakes region, where most terraces formed during glacial or postglacial times, the abundant coarse-grained material furnished by the melting ice has resulted in terraces in which materials tend to be sand and gravels. Many exceptions occur, however. Elsewhere terrace materials were controlled by more diversified conditions, and materials therefore vary more widely. In any event, the materials are often crudely stratified.

316. However, not all terraces are of alluvial origin. Some are composed of rock covered with a thin veneer of alluvium, or sometimes only by a residual soil. Such "rock-defended terraces" can often be identified

by examining the terrace edge for traces of rock outcrops. In addition, an abrupt change in direction of the valley stream channel as it impinges upon the terrace edge is sometimes an indicator of a rock-cored terrace.

317. Soil profile characteristics. Surface soils on terraces are generally well developed and quite thick. There is only a slight correlation between soil texture and topographic position. Soils on high positions in general consist of an A-horizon approximately 12 in. thick and composed most commonly of CL and SM soils, with SW, SP, SC, MH, and OH soils occurring in substantially lesser amounts. The B-horizon of high sites is generally richer in clay and more plastic than the A-horizon, and may be from 12 to 36 in. thick.

318. On low sites the A-horizon is generally from 6 to 18 in. thick, and is most commonly composed of OH and CL soils, with CH, SM, ML, and MH types occurring less frequently. The B-horizon is generally more clayey and somewhat more plastic than the A-horizon, and ranges in thickness from 30 in. to about 5 ft. In general, the OL and OH soils are confined to poorly drained depressions; these organic and plastic soils may be as much as 2 ft thick. Such hollows frequently contain a B-horizon consisting of mottled soils of high plasticity as much as 10 ft thick.

319. Trafficability and cross-country movement characteristics. The soils of the 47 terrace sites that could be classified fell into soil trafficability classes A (SW), B (CH), C (SC and CL), and D (SM, ML, MH, OL, and OH). Of these, 64% were in class D and 28% in class C. There is little correlation between soil trafficability classes and topographic position. In general, the following comments can be made:

- a. Class A soils (SW) are trafficable for all vehicle categories all year round, but only 2% of the sites examined fell into this class.
- b. Class B soils (CH) would be trafficable for all vehicles during the dry season, but going would be difficult or impossible for vehicle categories 4 through 7 during the wet season. Only 4% of the soils examined were of this class.
- c. Of the CL soils tested, 2 had wet-season RCI's of less than 50, 5 had RCI's that ranged from 50 to 100, and 5 had RCI's that were greater than 100. All low CL sites had RCI's less than 100 and their average RCI was 59. The one SC soil tested had an RCI in the wet season of 142. The high CL and SC sites usually have sufficient strength to support

all vehicle categories in the wet season except category 7. The low class C sites are trafficable to category 3 and less vehicles in the wet season. In the dry season most low sites may be trafficable to all except category 7 vehicles.

- d. Class D soils (SM, ML, MH, OL, OH) exhibit widely variable trafficability conditions. However, there appears to be a general relation with soil type and topographic position. The RCI's of all SM soils in the wet season regardless of location were in excess of 100. The OH soils have the lowest wet-season RCI for the class D soils, and the low OH soils are much weaker than the high OH soils. The high OH soils ranged in RCI from 57 to 102 and averaged 80. The low OH soil RCI's ranged from 18 to 121 and averaged 46; the next highest reading in this group was 62. The RCI of most of the other soil types in class D (OL and MH) approximated 75 during the wet season. In terms of wet-season trafficability for class D soils, the SM soils are trafficable to those vehicles whose VCI requirements do not exceed about 110. The high OH soils are trafficable to category 1, 2, and 3, and some 4 vehicles; the low OH soils are trafficable to category 1 and some category 2 vehicles. The MH and OL types are passable to category 1-4 vehicles.

320. Slopes and vegetation would not ordinarily be an inhibition to movement on terraces. However, the terrace edges, and the bounding valley wall (if one is present) may in some places be sufficiently steep to be an inhibition, or even to stop vehicular movement across them.

Coastal alluvial plains

321. Coastal alluvial plains include all landscapes that have been constructed chiefly by fluvial process, and that occur along or near coastlines. In this report, however, only coastal swamps, marine terraces, and some undifferentiated surfaces of low relief are included. Many other landscapes, such as bayed plains, are not incorporated in this report because of lack of data thereon.

322. Many landscapes that are normally included in general descriptions of "coastal plains" are excluded from this category. For example, cuestas and the karstic limestone plains of Florida are omitted because they owe their present shapes primarily to erosional rather than depositional processes.

323. Regional drainage.

- a. Coastal swamps. The gross drainage pattern is fundamentally dendritic, but many variations occur. Because many

coastal swamps are saucer-shaped, even though of very subdued relief, the gross drainage pattern may be roughly centripetal; it might require examination of a very large area for this trend to be noticeable. Tendencies toward deranged and reticulate patterns are common. Channels are usually meandering or tortuous, with widely variable widths; they sometimes appear to vanish without trace. The low-order drainage patterns are usually basically dendritic, but in many places they are completely concealed by dense vegetation, as pointed out by the marginal arrows in fig. 33.

- b. Marine terraces. The gross drainage pattern is generally crudely parallel, while the low-order drainage patterns are usually dendritic. In some places, however, scour channels may be entirely absent, as illustrated by the lower left corner of fig. 33.
- c. Undifferentiated surfaces. Both the gross and low-order drainage patterns may be widely variable; dendritic is predominant.

324. Topography.

- a. Coastal swamps. The cross-sectional shape is undulating. Relief is rarely more than a few feet, and is commonly only a few inches. Coastal swamps range in size from a few hundred square yards to many square miles, and in shape from the almost perfectly elliptical Carolina "bays" to such exceedingly irregular varieties as the Dismal Swamp.
- b. Marine terraces. The cross-sectional shape is either undulating or blocky. Relief is commonly variable, ranging from a few feet to several tens of feet. The terrace surface is widely variable in size, ranging from a fraction of a square mile to a broad belt of territory several square miles in area. Slopes are commonly less than 10%, including the seaward terrace edge.
- c. Undifferentiated surfaces. The cross-sectional shape may be undulating, rolling, or blocky. The latter type is illustrated in fig. 34; note the relatively abrupt valley walls and the flat uplands. Both erosional and depositional processes are probably equally responsible for their existing form. Relief may range from 10 ft to as much as 100 ft, although the latter is rare.

325. Local erosion.

- a. Coastal swamps. No gullies or other forms of local erosion occur.
- b. Marine terraces. Gullies are relatively rare on these surfaces. When they do occur, the most prevalent is the F type, which appears to develop chiefly in clayey sands. The normal V-type gullies with steep gradients develop

in terraces composed of gravels and sands. Compound types also occur, depending upon the precise nature of the component soils and parent materials.

- c. Undifferentiated surfaces. Gullies in this surface type may be of virtually any form. Complex types (i.e. F and CF types) are relatively common, as are the more normal, simple types. Evidences of rill and sheet erosion are common.

326. Natural vegetation.

- a. Coastal swamps. These surfaces are generally heavily forested in humid-temperate climates. However, some areas, especially those adjacent to lakes or streams, may be covered with dense stands of grasses and reeds. In some places the surfaces of lakes and even streams may be partially or completely obscured by floating vegetation.
- b. Marine terraces. These surfaces were (and in many places still are) forested. In general the forests are relatively open in humid-temperate climates, and the ground can be seen from above through gaps in the tree canopy.
- c. Undifferentiated surfaces. These surfaces were almost completely forested in humid-temperate climates.

327. Land use and construction practices.

- a. Coastal swamps. These areas are rarely used for agriculture, although they have been artificially drained in some places. In such instances, the crops are usually truck crops, and normally result in a distinctly linear texture on photos. Roads normally avoid these areas. Where necessary, roads cross them in straight lines and are usually so placed as to avoid the lakes and large streams, if possible. Some areas of this type are logged, and the resulting camps, logging roads, and spur railroads produce distinctive patterns on airphotos.
- b. Marine terraces. These areas are cultivated in many places, forested in others. These usages intergrade; in some areas there are only clearings in the forest; in others there are patches of forest surrounded by cultivation. Fields are generally rectangular, but there is generally a tendency for field margins to be aligned roughly with the ridge or stream lines. Crops are commonly diversified; resulting in wide variations of photo tones and texture. Both contour plowing and artificial terracing are widely practiced. Roads are commonly independent of terrace topography. The occasional presence of a gravel or sand pit generally indicates parent materials of relatively clean sand or gravel. However, these must not be mistaken for the very common borrow pits from which silty and clayey sand and gravels are taken for the construction of fills and embankments.
- c. Undifferentiated surfaces. The land-use patterns of these

surfaces are closely similar to those of the marine terraces. Roads commonly tend to follow ridge lines, and to cross intervening valleys at more or less right angles. Borrow pits are relatively common, but gravel and sand pits are rare.

328. Parent materials.

- a. Coastal swamps. Parent materials are chiefly thinly and irregularly stratified silts and clays. Sands and silty sands occur in some places, chiefly near the edges of the basin in which the swamp occurs.
- b. Marine terraces. Parent materials are widely variable, ranging from nearly clean gravel to silty clays. The unconsolidated materials are usually crudely stratified. Some terraces are rock-cored, and covered with either a thin veneer of alluvium or only a residual soil formed directly from the rock. Generalization is difficult, but the following comments apply, although exceptions are numerous:
 - (1) Sand parent materials rarely exhibit gullies.
 - (2) The wider the spacing of drainageways the more permeable the parent materials. Gravels are not necessarily permeable, because the clays produced by weathering may inhibit soil water movement.
 - (3) V-type gullies normally imply gravelly sand or silty sand parent materials.
 - (4) F-type gullies normally imply silt, sandy, or sandy clay parent material.
 - (5) C-type gullies normally indicate clayey, cohesive materials, but not necessarily parent materials of this description. The gullies may form on the weathered profile alone; such cohesive surface soils frequently form over gravels.
- c. Undifferentiated surfaces. Parent materials are highly variable, both in grain size and degree of induration. Some are so indurated as to warrant classification as rocks. Gully forms can be used to identify parent material types in the same fashion as for marine terraces. However, the degree of induration makes this technique of doubtful utility in some places.

329. Soil profile characteristics.

- a. Coastal swamps. Soils of coastal swamps were tested in only three sites, far too few samples from which to draw generalizations. The soils tested were Pt, OH, and SM-SC types in the 6- to 12-in. layer. Peat and mucks (Pt) may in some places be many feet thick. The highly organic soils are commonly underlain by impermeable plastic clays

and silty clays. Internal drainage is very poor.

- b. Marine terraces and undifferentiated surfaces. These surfaces were not differentiated at the time soil tests were made. The similarity in parent materials, and the weathering processes to which both have been subjected make it likely that similar soil types have been developed on both. One other peculiarity of these surfaces must be kept in mind. Most topographically low positions in these areas are actually the floodplains of small streams. The materials and soils are therefore not precisely comparable to those of the topographically high positions. The high sites are valid marine terraces and undifferentiated surfaces, but the low sites could quite properly be classed as floodplain soils. They are combined in this section largely for convenience, and because their geographic locations are so closely related.

330. The A-horizon is normally from 6 to 36 in. thick. This horizon is widely variable, depending upon parent material and depth of weathering. The most common soil types are SM (21% of the classified samples), CL (21%), SP (17%), and ML (17%). Other types found relatively infrequently are CL-ML, MH, SC, SW-SM, and SP-SM. The A-horizon is often underlain by a somewhat more clayey and plastic B-horizon, which in many places is very thick. In a few places, such as in northern Florida and southern Georgia, an organic, impermeable hardpan is commonly found at depths of from 12 to 36 in.

331. Trafficability and cross-country movement characteristics.

- a. Coastal swamps. The soils of this landform were of soil trafficability classes D (SM-SC and OH) and E (Pt). They remain wet or saturated all year, and the limited available data indicate that these soils would be untrafficable at any time to vehicle categories greater than 4. Swamp vegetation will seriously inhibit or even stop vehicular movement in many places.
- b. Marine terraces and undifferentiated surfaces. The soils of the surfaces tested were fairly well distributed into three soil trafficability classes: class A (SP and SW-SM) for 19% of the samples, class C (SC and CL) for 34%, and class D (SM, ML, CL-ML, MH, and SP-SM) for 47%. There is a general correlation between topographic position and soil type or trafficability class.

332. For the class A soils the high site had a higher cone index than the low site; however, all sites were strong enough to support all vehicle categories in all seasons. Wheeled vehicles will experience some

traction difficulties if they are operated at high tire pressures.

333. Class C soils were somewhat more variable. These soils exhibited wet-season RCI's of 126 and greater for the high sites and a range of 44 to 166 with 9 of 12 site readings being less than 100. The high sites would be trafficable to vehicles whose VCI requirements are less than 120. Most of the low sites would be trafficable for vehicle categories 1, 2, and 3, and marginal for category 4 vehicles, while others would apparently be trafficable for all vehicle categories.

334. Class D soils were also exceedingly variable, both as a class and within individual soil types. The SM soils exhibited RCI values ranging from 139 to 254 during the wet season for the high sites and 33 to 300+ for the low sites. The high sites would apparently be trafficable for all vehicle categories. The RCI values of three of the low sites were less than 75, indicating that some areas would be impassable to vehicles in categories greater than 5. Some low, wet areas will only permit vehicle categories 1 and 2 to pass. The ML soils in high topographic positions are generally trafficable for all vehicle categories except 6 and 7 since the RCI values usually exceed 90. In low, poorly drained areas the RCI ranged from 43 to 89 during the wet season; thus, such areas are trafficable for category 1-3 vehicles and marginal for category 4.

335. Topographically high areas, while not significantly different in soil types or trafficability classes, are still considerably more trafficable than low areas. Opportunity for drainage induces more rapid soil drying, which alone would serve to make nearly all high sites trafficable within a few days after a saturating rain. The low sites, on the other hand, drain very slowly, and in fact may remain wet all year, resulting in perennially poor trafficability conditions.

336. Slopes on marine terraces and undifferentiated surfaces are rarely steep enough to stop vehicular movement, but they are frequently steep enough to inhibit it appreciably. Slopes of 30% are frequent enough to deserve consideration. Gullies along terrace edges, and along valley walls of major streams, are commonly deep and steep enough to stop vehicular movement. The forests on these surfaces are normally composed of trees spaced so widely that they would not inhibit movement.

Landscapes in Lacustrine Deposits

337. Landscapes in lacustrine deposits are those which owe their essential shape to deposition from standing water, either salt or fresh, and either perennial or ephemeral. Such surfaces are commonly somewhat modified by subsequent erosion; however, if the original depositional surface is recognizable, it is classified herein as a lacustrine landscape. Such surfaces are widely distributed on every continent (see fig. C4). They are, essentially, the dry beds of lakes.

Beds of perennial lakes

338. These landscapes are in general the beds of large freshwater lakes which have been drained within geologically recent time. A few surfaces of this general type are the result of deposition from brackish or saline water. Lacustrine surfaces are most common in and adjacent to glaciated regions; excellent examples occur in the Great Lakes region, as well as in northern Europe and Asia. The larger lake beds are normally bounded in at least a few places by abandoned beaches and beach ridges (for discussion of which see section on "littoral landscapes"). However, small examples of this type may exhibit no perceptible marginal features.

339. Regional drainage. The gross drainage pattern is generally basically dendritic, but in cultivated regions it is usually ditched or canalized so completely as to be difficult to recognize. In some places only the trunk stream is in a natural channel; the channels of such streams tend to be of the meandering type. Low-order drainage patterns are generally of the ditched or tiled type if the region is cultivated (as illustrated in fig. 35), and dendritic if it is not.

340. Topography. The cross-sectional shape is generally undulating. Beds of perennial lakes are commonly so flat that no relief can be seen with a stereoscope. However, some surfaces of this type exhibit subdued mounds or ridges of irregular configuration. Local relief rarely exceeds a few feet, and in many places is imperceptible even on the ground. Slopes are very gentle, rarely exceeding 5%.

341. Local erosion. Where gullies occur, they generally are very broad C type, with very flat gradients, as illustrated by marginal arrows A in fig. 35. Lack of gullies, as shown in the center portion of

fig. 35, normally indicates lack of available relief, rather than lack of susceptibility of the soils to erosion. Where there is sufficient relief, such as along major river valleys, gullies are very common. Where gullying occurs, sheetwash is normally important, and is indicated on airphotos by light photo tones on the sides of small stream valleys and gullies, as in the upper right corner of fig. 35.

342. Natural vegetation. In humid and subhumid regions, lake basins were covered with forest or marsh, depending upon the drainage. In semi-arid regions such basins were commonly grass-covered. Most lake basins are now so intensively cultivated that little or no trace of the original vegetation remains.

343. Land use. Field patterns are almost entirely rectangular, and independent of topography or drainage. Most lacustrine plains in humid climatic regimes are intensively cultivated. The wide variety of crops grown results in a distinctly checkerboard effect of dark and light photo tones, as illustrated in fig. 35. Wood lots, which photograph dark with botryoidal texture (as opposed to cultivated fields, which photograph with smooth or faintly linear textures), are normally few and scattered in such regions. However, in some places forest cover is extensive; this is usually an indication of a high water table and waterlogged soils. Grass, with some cultivation, is the normal cover in semiarid regions.

344. Construction practices. Roads are generally in a rectangular pattern and independent of topography or drainage. In rural areas clusters of farm buildings are common, as illustrated in fig. 35. It is not uncommon for all stream channels except major rivers to be artificially straightened and deepened. Note the abnormally straight or smoothly curved drainage lines exhibited in fig. 35. Tiling is common, but may be very difficult to detect, especially in photos taken during summer, fall, and winter; in spring the drying effect of the tiles commonly produces a faintly streaked pattern running across the fields.

345. Parent materials. Most lake beds are composed of considerable thicknesses of stratified materials. The materials are generally relatively uniform in any given area, but vary widely from district to district. Materials range from heavy clay through silt-clay mixtures to silts and even sands. Sands, however, are relatively rare, although very subdued

fixed dunes or sand ridges and sheets of irregular shape and limited extent are sometimes superimposed on a surface composed of fine-grained material. Such features are rarely more than a few feet high. In some lake basins there is a consistent gradation from sands or silty sands at the margin through silts to clays at the center. Sandy parent materials are also common where streams reach the outer margin of the lake basin.

346. Soil profile characteristics. Soil profiles are generally from 30 to 36 in. thick. The A-horizon may be from 6 to 20 in. thick, but it may be much thicker in peat or muck areas. The B-horizon is commonly slightly more plastic than the A-horizon. Hardpans may occur at depths of from 20 to 36 in. in poorly drained areas. Peat and muck soils may reach depths of several feet. Soil types include: slightly to highly silty or organic sand (SM or SP-SM), clayey sand (SC), silts, clays, and silty clays of many types (ML, CL, OL, MH, CH, OH, and ML-MH), and peats and mucks (Pt). In general, the sandy and silty types tend to occur toward the margins of the drained lake basins, and the clays and peats toward the center, but many exceptions occur.

347. There appears to be no significant correlation between soil type and high and low topographic positions, with the exception of Pt soils, which are confined to low positions with poor drainage. Further, there is no apparent correlation between soil types and climatic regimes. In any given district there appears to be a faint tendency for soils on high topographic positions to be slightly coarser grained than those in the adjacent lows, but the distinction is not sufficiently marked to result in a notable difference in soil types.

348. Local differences in soil type reflect as faint mottlings on airphotos. The coarser-grained soils, which drain (and therefore dry) more readily than adjacent fine-grained soils, tend to photograph in light gray tones. The occasional dunes and sand sheets photograph as "smears" of light photo tones against the generally dark tones of the finer-grained surface soils. The light area indicated by marginal arrows B in fig. 35 is a sandy zone. Organic soils are darker in color and retain water longer than other soils, and therefore photograph dark, so that the bottoms of gullies or other hollows may be distinct on a photograph even though their relief is commonly so subdued as to be undetectable by

stereoscopic examination. For example, note the gully marked by marginal arrows A in fig. 35.

349. Depending on soil type, the internal drainage may be good to very poor. However, the generally low relief is often an inhibition to both internal and external drainage, with the result that soils of lake basins frequently retain high moisture contents throughout the year.

350. Trafficability and cross-country movement characteristics.

Lakebed soils fell into soil trafficability classes B (CH), C (SC and CL), D (SM, SP-SM, ML, ML-MH, MH, OL, and OH), and E (Pt). With the exception of class E soils, there is no apparent correlation between classes and either topographic position or climatic regime. Class E soils occurred only in low topographic positions. Of the 78 sites tested, 14% were in class B, 28% in class C, 53% in class D, and 5% in class E.

351. The wet-season RCI's for the class B (CH) soils were slightly greater than 100 for both the low and high sites. These soils will be sticky and slippery when wet but trafficable to all vehicles except to those vehicles in category 7 whose VCI's exceed about 110. In class C, the SC soil's RCI's were somewhat higher than those for the class B (CH) soils. The RCI's for the CL soils of this class (C) ranged from 64 to 169 with an almost equal number of samples falling into the 64-100 and 100-169 ranges. The RCI's in the low sites were about 20 points lower than for the high sites. In the wet season many areas containing CL soils will be trafficable by all vehicle categories, but many other CL areas will only be passable for 1-4 category vehicles. For the class D soils, the test results indicate that the high sites will be trafficable in the wet season by all vehicle categories except 7; however, for the low sites most areas will be limited to vehicle categories 1 and 2. Of the class D soils the ML and OH gave the lowest RCI values. They ranged from 16 to 118 with 7 of 14 RCI values being less than 50. The RCI for the OL, SM, and MH soil types ranged from 54 to 118.

352. Slopes are generally so gentle (i.e. less than 5%) that they do not impede vehicle movement. Only along the valley sides of major rivers will slopes be found that are steep enough to inhibit movement; in such places, the combination of slopes and slippery and sticky soils during periods of high soil moisture content may be a serious obstacle. The

artificially deepened ditches would be an obstacle to movement of wheeled vehicles almost everywhere, and in some places they are wide and deep enough to stop even tracked vehicles. Vegetation is not normally a problem; even in heavily forested areas the trees are generally rather widely spaced.

Beds of ephemeral lakes (playas)

353. Surfaces of this type develop wherever closed basins occur in arid climates. They are essentially nothing more than the beds of lakes which contain standing water for only a short time each year; some, in fact, may contain water only once in several years. Playas occur in every major desert area in the world. In the United States they are most common in Utah, Nevada, and California, but they are also present as far east as western Texas and as far north as Washington. They range in size from a fraction of a square mile to several hundreds of square miles, and in shape from almost symmetrically elliptical to widely irregular. The edges are often indistinct, as illustrated by the examples in fig. 36, and rarely if ever exhibit the shore features of permanent lakes.

354. Regional drainage. The drainage features of playas are exceedingly variable, depending on the type and location of the surface. Some types exhibit gross and low-order drainage patterns that strongly resemble marshes in humid regions (except that they are devoid of vegetation). For example, compare the tonal variations of the delta surface in photo c of fig. 31 with the lower half of photo a of fig. 36. The drainage is often contorted and reticulate, as illustrated in photo a of fig. 36, with channels fading out into the general surface in many places. In others, the surface may be virtually featureless, as illustrated in the upper half of photo b of fig. 36. In a few places, the surfaces are sufficiently concave to develop rudimentary centripetal patterns, especially near the margins. In most cases, as in both examples in fig. 36, the channels are so shallow that they show only as tonal variations. Relief is so minor in most instances that the entire surface is inundated by relatively modest amounts of water.

355. Topography. Most playa surfaces are very nearly flat. In detail they are commonly gently undulating and channeled, but this relief is normally so subdued that it is undetectable stereoscopically, as

illustrated in photos a and b of fig. 36. The surfaces, being the floor of an ordinarily much larger basin, are often very gently concave upward. The surfaces are bordered in most instances by the lower slopes of alluvial aprons or fans, as illustrated at the left and top of photo a, fig. 36. The gradation from apron to playa is commonly indefinite, as shown in photos a and b, fig. 36. Small (i.e. a few inches or feet high) and irregular mounds occur on some playa surfaces, and in many places dunes may also be present, as illustrated by the small "turret" dunes indicated by marginal arrows B in photo b of fig. 36.

356. Local erosion. Relief is ordinarily far too low to permit the formation of gullies in the normal sense, although short, rudimentary channels are not uncommon on some types. Some wind erosion and deposition may occur in places where the soil is noncohesive, as illustrated by the very small dunes on the playa surface in photo b of fig. 36 (indicated by marginal arrows B). The more usual situation is the formation of dune fields on the margins of the playa, as illustrated in the lower left corner of photo b, fig. 36.

357. Natural vegetation. Playa surfaces exhibit widely variable vegetation patterns. Those with very high salt contents, such as that illustrated in photo a, fig. 36, are normally devoid of vegetation. Such surfaces may have zones of shrubs along their margins, as shown by the area in photo a, fig. 36, identified by marginal arrows A. Playas in which the salt concentration is less than the salt tolerance of desert plants will support vegetation, provided the soil is not so compact or impermeable that plants cannot obtain a foothold. This situation is common in basins where at least part of the water is lost through internal drainage. Unfortunately, the balance of conditions controlling plant growth is so sensitive that several variations may occur on the same playa surface, as is illustrated in both photos a and b of fig. 36. Thus, the distribution of vegetation is commonly a sensitive indicator of soil moisture conditions, and/or of soil salinity.

358. Land use. Playas are not normally used for agriculture, although notable exceptions occur. In general, they show no traces of human interference, as illustrated in photos a and b, fig. 36. In those areas where playas are used for agriculture, such as parts of the bed of

Tulare Lake, California, the implication is that the soil is essentially silt or silty sand, and that it is nonsaline. Field patterns are rectangular.

359. Construction practices. Most playas are devoid of commercial or industrial works. However, a few are mined for such minerals as borax and salt. A few playas are also used as airfields, racetracks, or the like, for which the virtually plane surfaces are ideal. If cultivated, playas are invariably irrigated, and in such instances the presence of either irrigation or drainage ditches, or both, is a primary recognition feature.

360. Parent materials. The parent materials of playa plains are almost entirely fine grained, although lenses of sand, and sometimes even boulders, may occur in a few places. Many playas lose water only through evaporation, and in such instances the fine-grained alluvium may be mixed with a wide variety of evaporites, such as salt, anhydrite, and borax. In some places considerable thicknesses of nearly pure evaporites may occur. Soils with high salt contents often show striking tonal variations, as illustrated in photo a, fig. 36. Almost uniform tones of medium gray, as in photo b of fig. 36, usually imply predominantly silt with only minor amounts of salt, if any.

361. Soil profile characteristics. The surface soils of playas are of many types, depending upon the internal drainage characteristics of the basin, the nature of the surrounding uplands, and the amount of runoff reaching the playa. Because all these conditions tend to be similar for any one area, there is a marked tendency for any single playa to be relatively homogeneous throughout its extent, although notable exceptions occur, especially in the larger ones. The majority (59%) of the sites tested had soils classified as CL; next (14%) were SM soils. The remaining types (GP, CH, ML, MH, OH, and salt) were confined to single test sites and they comprised 27% of the sites tested. The number of samples taken and the non-representativeness of the test site distribution make it impossible to generalize on a regional basis. The percentage of soil material less than 0.002 mm in size ranged between 21 and 86%. A notable exception is a playa in Kings County, California, in which more than 47% of the soil consisted of material larger than 0.05 mm. In general, the sandy soils, such as SM types, were found near the border of the playas. In a few places dunes and

sand sheets occur on playas, and in one locality (Tooele County, Utah) eolian erosion was sufficiently severe to produce lag gravels (GP) (i.e. layer of pebbles on the surface of fine-grained materials) on the surface.

362. Fine-grained playa soils often develop firm surface crusts. Depending upon internal drainage and other factors, the crust may be silty clay, or it may be silt and clay cemented with salt, or in rare cases it may be virtually pure salt. Such crusts may be thick or thin, clay or salt, depending upon delicate and poorly understood balances between internal drainage, evaporation, soil type, and incident water.

363. Trafficability and cross-country movement characteristics. Playa soils fell into soil trafficability classes A (GP), B (CH), C (CL and salt), and D (SM, ML, MH, and OH). Unfortunately, the peculiar properties of playa environments, including the cementation properties of mineral salts, make these classes largely meaningless on playas. In general, playas in which the water table is high (i.e. within a few feet of the surface) have poor trafficability characteristics, particularly if the soil material is fine grained or sand mixed with sufficient fines. For example, a "moist" playa in Nevada (Washoe County) had an RCI of only 18. Similar playas in Kings County, California (under cultivation and after severe flooding), exhibited RCI's of only 18 and 19. It is evident that such playas are, for all practical purposes, untrafficable for all vehicles. Moist playas can be identified on airphotos by their dark photo tones, in contrast to the very light gray or white tones of dry playas. This criterion should be used with caution, however, because some moist playas develop a very thin (i.e. less than an inch) crust of perfectly dry, salt-cemented materials which photograph in very light tones. Such crusts will generally not support a vehicle.

364. Playas with thick salt crusts, as for example the famous Bonneville Salt Flats in Tooele County, Utah, are among the most trafficable surfaces in the world. At the time this site was tested, the playa contained a foot of water, but the surface was impenetrable with a cone penetrometer. The Kern County, California, playas consist chiefly of CL soils that are so firmly cemented and so flat that they constitute a natural runway surface 12 miles long and up to 5 miles wide capable of sustaining the heaviest existing aircraft. At the time of the tests for this

report, about half the surface was covered with a few inches of water. The surface was soft and slippery to depths of about 3 in., below which the soil could not be penetrated with the cone penetrometer.

365. Traction is poor on most fine-grained playa surfaces when the surfaces are wet, but the bearing capacity will in most cases be adequate to support even the heaviest vehicles. The exceptions to this generalization are, of course, those playas having high water tables (i.e. the moist playas). Moist playas, other than those irrigated, usually are bordered by alluvial aprons less than 1 mile in width.

Landscapes in Littoral Materials

366. Landscapes in littoral materials are those which owe their fundamental shape, parent materials, and distribution to littoral processes (chiefly wave, current, and tidal actions). Such landscapes occur along the present shorelines of oceans, seas, and large lakes, and are common at abandoned shorelines. In this report, tidal flats and beach ridges are classed as littoral landscapes, and are discussed below.

Tidal flats

367. Tidal flats occur along any marine coastline that is subject to an appreciable tidal range, but which is not subject to vigorous wave attack. They are, therefore, most common in sheltered bays and estuaries, or bordering tidal lagoons. They are also most common on coastlines that have recently been inundated by the sea (i.e. the so-called "drowned coasts"), but small examples may occur on virtually any type of coastline. They range in size from an acre or so to several tens of square miles.

368. Regional drainage. The gross drainage pattern is reticulate, similar to that illustrated in photo a of fig. 31. Channels are usually meandering, and are generally narrower at the bends than in the reaches. Low-order drainage patterns are normally dendritic. The drainageways are commonly very closely spaced, as well as being abnormally large for the area being drained. The entire surface is flooded for at least a few hours during the year during spring tides, and in most cases it is flooded at least once each day during high tide. Channels are distinct and relatively permanent when the surface is vegetated, similar to that illustrated in

photo a of fig. 31, but may be indistinct and ephemeral when vegetation is absent.

369. Topography. The cross-sectional shape is undulating, but relief is so subdued that it rarely if ever exceeds a few feet. The surface is normally almost a plane, scarred only by drainage channels.

370. Local erosion. Relief is too low to permit any form of gully, rill, or sheet erosion. Minor runoff channels form on nonvegetated surfaces immediately after the ebbing tide; they are normally visible on air-photos as subparallel dark streaks that fade indeterminately into the surrounding light-toned flats.

371. Natural vegetation. The type of vegetation is controlled by climate, tidal range, tidal regime, and water salinity. In temperate zones, flats with relatively small tidal ranges are generally covered with a more or less dense growth of reeds and tall grasses, grading off into shallow but permanently flooded areas of purely aquatic plants. The resulting photo tone is generally dark with an almost smooth texture. In areas where the tidal range is large, the tidal flats may be completely barren, except for stranded marine plants. Examples occur on the Bay of Fundy in North America, and on the Brittany coast in Europe. In subtropical and tropical regions, tidal flats are commonly forested with mangrove. These forests photograph dark with a very distinct botryoidal texture. Examples occur in southern Florida. In areas where the tidal water is brackish, tropical tidal flats may be covered with varieties of palms and ferns.

372. Land use and construction practices. Tidal flats are rarely if ever used for agriculture. In the tropics mangrove forests are sometimes logged, primarily for fuel. Otherwise tidal flats are rarely modified by human activity. In some cases, however (for example, in New Jersey), tidal flats have been ditched in an effort to improve drainage for public health reasons.

373. Parent materials. Parent materials are widely variable depending upon the type available for transport by littoral and tidal currents, and also depending to some extent on the magnitude of the tidal range and the vegetation cover. In general, all tidal surfaces are sand, sandy gravel, or silty sand, but this material may be masked by exceedingly variable thicknesses of surface materials. Where tidal ranges are low and

vegetation cover is dense, there may be a considerable thickness (up to several feet) of silt or silty sand. Where vegetation is sparse but tidal range is low, the material tends to be more sandy. Where extreme tidal ranges occur, the materials are almost invariably relatively clean sand or even gravel.

374. Soil profile characteristics. Tidal flats rarely have an appreciable development of soil profile. Nonvegetated flats have none; in such cases the soils are almost invariably uniformly graded clean sands. Vegetated tidal flats may have a thin surface layer (normally less than 2 in.) of organic sands or silts, overlying nonorganic sands or silty sands.

375. Trafficability and cross-country movement characteristics. No trafficability data were obtained from tidal flats. However, the soil types that occur most commonly (probably SP, SW, and SM) fall into soil trafficability classes A (SW and SP) and D (SM). Tidal flats rarely dry to depths of more than a fraction of an inch, and in general, therefore, have the trafficability characteristics of wet or moist clean sands or silty sands. However, in a few places such sands are quick, and in that state sands will not support vehicular movement. Fine sand (SP) areas found on lagoonal tidal flats may also liquefy under vehicular traffic, thus causing some vehicles to become immobilized in 5 passes or less. Vehicle tests conducted in one tidal flat area in connection with other studies revealed that the RCI averaged about 54. Such areas would be trafficable for vehicles in categories 1, 2, and 3.

Beach ridges

376. Beach ridges occur along most shorelines of low relief that are subject to wave attack. They occur on large lakes as well as along oceans and seas. They commonly form the margins of the larger lacustrine plains. Beach ridge complexes are widely variable in area, ranging from narrow bands a few yards wide to areas covering several square miles.

377. Regional drainage. This landscape type is usually too restricted in area to develop gross drainage patterns. Low-order drainage patterns are variable, depending on the age of the ridges, the parent materials, the climatic regime, and probably other factors. Relatively young beach ridges are commonly of the channelless basin type, the basins being elongate, roughly parallel swales. Old beach ridges may be this type, or

they may develop scour channels through the swales, resulting in collinear patterns. Very commonly the drainage is a combination of channelless basin and collinear types, as illustrated in the upper third of fig. 37, where indistinct and poorly developed drainageways occur in combination with undrained basins. Trunk streams, if present, may cut across areas of beach ridges, usually at nearly right angles.

378. Topography. The cross-sectional shape is frequently undulating. The arcuate or sinuous ridges may range in height from a few feet to as much as 30 ft, but the normal range is less than 10 ft. The parallel ridges are separated from each other by swales. The slopes exhibited by beach ridges are the result of complex interrelations between parent material type, mode of origin, and age. In general, the following generalizations can be made, but it must be recognized that many exceptions occur.

- a. The coarser the material the steeper the slopes. Gravel ridges may have slopes as steep as 60% in some cases, although most are much less.
- b. The older the ridge the more gentle the slopes. Those ridges closest to the shore (i.e. the youngest) are commonly appreciably steeper than those farthest from the shore (i.e. the oldest).
- c. Ridges formed on lakeshores or coastlines subjected to ice push are often steeper than those formed by wave action alone.

379. Local erosion. Beach ridges rarely if ever exhibit gullies. Where vegetation is absent they are subject to wind erosion. The presence of deflation hollows and incipient dune formation is indicative of sand as a parent material.

380. Natural vegetation. Vegetation varies markedly depending upon climate and local environment. Along exposed coasts, beach ridges are commonly covered with sparse grass and shrubs. In humid regions, areas of beach ridges far from present shorelines may be forest-covered, and in such cases, the subdued topography may be entirely masked by the trees. This situation is also common in areas of beach ridges bordering large lakes or lacustrine plains. In semiarid regions the normal vegetation is sparse grass and scattered shrubs.

381. Land use. Areas of relatively recent beach ridges are rarely used for agriculture. However, areas of ancient beach ridges are commonly

cultivated, as illustrated in fig. 37. In such instances the topography is normally so subdued that field boundaries are rectangular and independent of the topography. However, in some places the markedly different soil properties between swales and ridges result in field patterns aligned with the trend of the ridges. The resulting alternations of light (the ridges) and dark (the swales) photo tones are sometimes striking.

382. Construction practices. Roads are normally independent of beach ridge topography. However, if the alignment of the ridges happens to trend in roughly the direction of the road or railroad, the ridges are not uncommonly used as a ready-made embankment. Beach ridges are sometimes used as sources of sand and gravel for industrial purposes or road materials.

383. Parent materials. The parent materials are almost entirely coarse grained, ranging from gravel to fine sand. In some places, shells and shell fragments constitute an important fraction of the material. The materials are generally almost entirely free of fine-grained materials. In areas subject to ice push, even large boulders may be found incorporated in the ridges.

384. Soil profile characteristics. The surface soil profiles of beach ridges are dependent upon parent material and the age of the ridge. Those in process of formation, or at least of very recent formation, exhibit little or no soil profile development, whereas old ridges, such as those bordering the now extinct glacial lakes of middle North America, often exhibit relatively well-developed profiles. In general, the soils of the ridges are coarse grained, consisting chiefly of SP-SM, SC, and SM types in the 6- to 12-in. layer. However, very old beach ridges may, especially in semiarid climates, exhibit fine-textured soils in the 6- to 12-in. layer. Such an example occurs in Brown County, South Dakota, where the soil is of CH type. The swales (i.e. the topographic lows) contain somewhat organic soils, most commonly of SC, SM, and OH types. In regions where climatic and drainage conditions are conducive to the development of organic soils (as for example in Minnesota), mucks and peats (Pt) of considerable depth may be found.

385. In general, the coarse-grained beach ridge soils free of organic materials (i.e. SP-SM) tend to photograph in light tones, whereas the

fine-grained organic soils (i.e. OH and Pt) in the swales tend to photograph in dark tones. This distinction is illustrated in fig. 37. This difference is commonly accentuated by differences in soil moisture; the excellent internal drainage of the ridges results in low soil moisture content and light photo tones, while the poorly drained soils in the swales remain moist and photograph in dark tones. The resulting streaked pattern of alternating dark and light in concentric arcuate or sinuous patterns can commonly be used in assisting in the identification of beach ridges even when the relief is so subdued as to be undetectable stereoscopically.

386. Trafficability and cross-country movement characteristics. All beach ridge sites examined for this study were on the margins of lacustrine plains of glacial age, and have therefore been subject to a long period of soil formation. The following generalizations do not, therefore, apply to beach ridges of recent formation. Of the 14 sites tested for this report that could be classified as to soil trafficability class, 7 were in topographically high sites and 7 in low. There appears to be no correlation between trafficability class and topographic position: class D (SP-SM) and B (CH) soils occurred on highs, while classes C (SC) and D (SM and OH) were about equally divided between highs and lows, and class E (Pt) was restricted to lows.

387. The excellent drainage, either internally or externally, of the soils on high sites appears to result in such low soil moisture contents that these soils are trafficable for all vehicle categories in all seasons. The lowest RCI value recorded was 156 (in an SC soil). Areas where the soil is predominantly cohesionless sand, such as a few of the SP-SM soils, might provide poor traction for wheeled vehicles with high tire pressures (chiefly category 6 and 7 vehicles), especially on the steeper slopes.

388. The soils in low topographic positions are commonly relatively poorly drained. The resulting high soil moisture content, coupled with the relatively fine-grained soils and high organic content, results in RCI values ranging from an estimated 43 (in a Pt soil) to an estimated 111 (in an SM soil) during the wet season. It is probable that the Pt and some of the SM and OH soils will be untrafficable during the wet season for all except perhaps category 1 and 2 vehicles. The remainder will probably be trafficable in varying degrees, depending chiefly upon moisture content.

During the dry season most, if not all, soils of low sites will be trafficable for most vehicle categories, with the possible exception of the peats (Pt).

389. Vegetation would not normally be an obstacle to cross-country movement on beach ridges.

Landscapes in Volcanic Deposits

390. Landscapes in volcanic deposits are those which owe their fundamental shape and internal composition to pyroclastic materials. They may, of course, be materially modified by erosion subsequent to deposition. However, the original clastic materials must remain more or less unconsolidated. When such materials become firmly consolidated, they are considered to be stratified igneous rocks.

Pyroclastic cones

391. Landscapes of this type occur in volcanic regions throughout the world. The category includes those forms of volcanic deposition commonly called cinder cones and stratovolcanoes; that is, landscapes produced by the fall of fragmented material such as ash, cinder, pumice, and lapilli, and by occasional interbeds of fluid lava. It does not include the so-called "shield volcanoes"; these are included in this report in the section devoted to landscapes in consolidated materials. Pyroclastic landscapes are found in virtually all of the western states of the United States, including Alaska and Hawaii.

392. Regional drainage. The pyroclastic cone is usually too restricted in area to develop gross drainage patterns, although many exceptions to this generalization occur. The low-order drainage patterns on the exterior slope are almost invariably of radial type, as illustrated by the portion of the pyroclastic cone toward the bottom of fig. 38. In the interiors of the craters, the low-order drainage is of centripetal subparallel type, as illustrated in fig. 38. In some places, where lavas have flowed down the sides of the cone and distorted the normal drainage patterns, as on the portion of the cone toward the top of fig. 38, the drainage is a special variety of the deranged type. The flows may also exhibit a peculiar form of swallow-hole drainage, in which the channels vanish into so-called "lava tunnels."

393. Topography. The cross-sectional shape is commonly crested but such a generalized description is less than adequate. Where newly formed, the cones commonly exhibit distinctive bowl-shaped craters at the top, as illustrated in fig. 38. The individual cones are oriented along a more or less straight line in some places, but they occur at random in others. The individual cones vary in size from a few tens of feet to several thousands of feet high, and in diameter from a few yards to many miles.

394. Local erosion. On very new pyroclastic cones gullies are not common, chiefly because the porous materials drain internally so efficiently that surface water flows do not develop. However, even with the passage of a relatively short amount of geological time, enough weathering of surface materials occurs to produce weathered surface cones that gully rather readily. Such gullies are commonly V type with very steep gradients as illustrated in fig. 38. In general, the coarser the material the fewer the gullies. Single pyroclastic cones may show wide differences in gully formation, depending on the accumulation of the various types and sizes of ejecta particles. This feature is also illustrated in fig. 38.

395. Natural vegetation. The vegetation of pyroclastic cones is a function of age and the type of climate. On very new cones vegetation is sparse (see fig. 38) or even absent. This condition persists indefinitely in arid climates. In humid climates, such cones are rapidly covered with dense vegetation, the type depending on the specific climatic regime. Lavas generally remain vegetation free for longer periods than fragmental materials, chiefly because they resist the formation of adequate soil cover for longer periods.

396. Land use. Newly created pyroclastic cones are not used by man. However, the soils which eventually develop on them are commonly very fertile, and as a result the slopes of old volcanoes may be intensively cultivated. Artificial terraces are common, and tend to intensify the impression of concentric topographic forms common to virtually all pyroclastic cones.

397. Construction practices. Very little construction use is made of pyroclastics or lavas in the United States. These landscapes are avoided in road construction, if possible.

398. Parent materials. The parent materials of pyroclastic cones

are widely variable in grain size, mineralogy, and degree of consolidation. Mineralogically the materials may vary from extremely quartz-rich and generally light-colored materials such as phonolites and rhyolites, through intermediate forms such as trachytes and andesites, to quartzfree and generally dark-colored rocks such as basalt. Texturally the materials range from grains in the silt and clay range (ash) through all intermediate sizes to immense boulders. They range in degree of consolidation from completely uncemented materials, such as newly fallen ash or cinders, to solid and very hard rocks, such as lavas. The unconsolidated, fragmental materials can commonly be identified by the typically smooth, normally light photo tones, while lavas are normally typified by a "chaotic" or "ropy" texture (or pattern). Lavas commonly photograph in slightly darker tones than fragmental materials. These characteristics are illustrated in fig. 38; the side of the cone toward the bottom of the picture is composed chiefly of fragmental materials, while the side toward the top is chiefly lava. In large cones these materials are normally stratified. In even slightly eroded cones, such as that of fig. 38, these layers or strata can commonly be seen either as alternating bands of different photo tones, or as small topographic variations that generally (but not invariably) occur concentric to the crater. Both of these features are illustrated in fig. 38.

399. Soil profile characteristics. Soil profiles on pyroclastic cones are a function of the geological age of the materials, the mineralogy, and the climatic regime. In arid climates soils remain thin and poorly developed. However, in humid areas the fragmental materials may develop thick profiles very rapidly. In general, the quartz-rich, medium-grained (i.e. sand-sized) materials develop sandy soils, generally with a considerable silt or clay fraction, while quartzfree materials develop primarily silty and clayey soils. The B-horizon is generally slightly more clayey and more plastic than the A-horizon.

400. Trafficability and cross-country movement characteristics. Only three sites were examined that comprised pyroclastic materials. All three were of SM (soil trafficability class D) type. Despite the similarity in type, the samples exhibited considerable regional variation. The sample from Idaho, taken in an intermediate topographic position (i.e. on a slope), was appreciably coarser than the two soils from sites in Oregon.

The additional coarseness of texture probably accounts for the exhibited differences in RCI's. The Idaho sample exhibited an RCI in excess of 300 during the wet season, while the Oregon samples exhibited an RCI of 94 at a low site and 113 at a high site.

401. All vehicles could cross the Idaho site without difficulty. At the Oregon sites, however, category 7 vehicles and some category 6 vehicles would be unable to operate in low topographic positions, although nearly all vehicles except a few in category 7 could operate on topographically high sites. The steep slopes of pyroclastic cones, which in many places exceed 60%, could not be negotiated by all vehicles, and even much gentler slopes would be impassable in some places and at some times, chiefly because of loss of traction in dry sandy soils, or in slippery clay soils after rain. In densely cultivated areas terrace walls would form impassable barriers in many places. The deep and V-shaped gullies would also be difficult to impossible to cross in many places. Dense vegetation would be a serious inhibition in uncultivated areas in humid zones.

PART VI: LANDSCAPES IN CONSOLIDATED MATERIALS

402. These landscapes are in general those which owe their existing configuration to erosional processes acting upon consolidated materials. The mode of deposition of the parent materials is immaterial for the purposes of this report. However, the configurations of landscapes in rock are almost without exception modified by depositional features. For example, the larger (and probably most of the smaller) streams of even lofty mountain areas flow on alluvial deposits (i.e. floodplains). Thus, the differences between landscapes in consolidated as opposed to unconsolidated materials are largely ones of emphasis, with no clear line of distinction separating them. To be entirely rigorous, virtually all topographic lows would necessarily be classified as alluvial (i.e. a landform in unconsolidated materials). The landscapes discussed in the following paragraphs would then become assemblages of landscapes, some of which would be in unconsolidated and some in consolidated materials.

403. Landscapes in consolidated materials are strongly controlled by both the nature of the materials from which the form is being sculptured, and by the gross structure (i.e. the attitude of the component rock masses with respect to the horizontal) of the rocks or other materials. Accordingly, the classification used in this report is primarily based upon three factors: (a) stratification or its absence; (b) structure, or attitude of the beds, if any; and (c) lithology, or the nature of the component rocks or other materials.

404. The various lithologic types which occur most frequently either alone or in combination are described separately. The classification used herein is given in table 7. The trafficability conditions described in each section are based almost entirely on the residual soils developed by weathering of the specific rock types to which the section is devoted. Bare rocks are not considered. As already pointed out, in many instances, and probably in most, the soils of topographically low sites have actually formed on a type of alluvial deposit. However, because these soils are commonly so closely related to those of the surrounding uplands, at least in the sense of having a common parent material, they are described here as a part of the regional properties.

405. As used in this report, consolidated materials are those which are so strong that they cannot be broken or deformed by the fingers. Hereafter these materials will be called rocks.

Landscapes of Low Relief in Horizontally
Stratified, Sedimentary Rocks

406. These landscapes are those normally called "plains." They have a local relief of less than 500 ft. The component rocks may be of any lithologic type, excluding igneous or metamorphic rocks. For the purposes of this report, horizontal implies that the bedding planes are not inclined at angles of more than a few degrees.

Limestone plains

407. Limestone surfaces of low relief are found in many parts of the world. In the United States excellent examples occur in Indiana and Florida. These are the widely known "karst" surfaces.

408. Regional drainage. Both gross and low-order drainage patterns are chiefly of the swallow-hole type. The through-flowing surface streams, if present, are usually more or less entrenched, such as the one illustrated in photo b of fig. 39. At least a few of the basins normally have short, low-order drainage channels leading to them, although in many places, for example in photo a of fig. 39, they are scarcely more than rills or gullies. Where well developed, they are usually dendritic.

409. Topography. The cross-sectional shape is typically undulating, as illustrated in photo a of fig. 39, but it may also be blocky as illustrated in photo b of fig. 39. Basin development is widely variable, ranging from a few, widely spaced, saucer-shaped depressions to very numerous, cup-shaped or cylinder-shaped "sinks." Photo a of fig. 39 illustrates an intermediate type. Basins are variable; they range in size from a few to a hundred yards or more in diameter, and in shape from nearly round to elongate or irregular. Local relief rarely exceeds 50 ft, but may be much greater. In general, but by no means invariably, the sinks of humid regions are saucer-shaped, while those of arid regions are bowl- or well-shaped. The walls of through-flowing streams are often very steep-sided, and may even be vertical in places.

410. Local erosion. Gullies are normally present, leading to at least a few of the basins or sinks. These are of a form intermediate between the normal V and C types, and are often arranged in a centripetal pattern around the sinks. There is normally little or no evidence of rill or sheet erosion.

411. Natural vegetation. The natural vegetation of limestone plains is only partly controlled by climatic regime. The excellent internal drainage, normally caused by a combination of blocky soil structure and the solution channel-riddled underlying limestone, results in abnormal soil aridity. Thus, although forest cover in temperate-humid climates is the normal condition, savannas and even prairies may occur. Forests on limestone tend to be "impoverished" (i.e. trees are relatively small and widely spaced).

412. Land use. Limestone plains are normally intensively cultivated. In the United States the field patterns are primarily rectangular and essentially independent of the topography, as illustrated in photo a of fig. 39. The soils and drainage conditions peculiar to limestone plains commonly result in the growing of a limited variety of crops, resulting in a tendency for these plains to photograph in relatively uniform tones and textures, as illustrated in photo b of fig. 39. Orchard crops are common where the climate is suitable. Limestone regions of this type are devoted to dairying and animal husbandry in places; the smooth photo textures of pastures are usually striking, as are the buildings peculiar to the dairy industry.

413. Construction practices. Roads and railroads are normally independent of the topography, as illustrated in photo a of fig. 39. However, the alignments are adjusted in some places to avoid particularly large or deep sinks, and major valleys. Quarries are common in some localities; they can normally be differentiated from sand and gravel pits by the usually vertical walls, and by the nature of the associated machinery. Straight quarry faces imply building stone, and therefore a massive, relatively pure stone. Irregular quarry faces normally imply use of the stone for road material, or industrial purposes, and no conclusions can be drawn as to quality of stone.

414. Parent materials. Parent materials are nearly horizontal beds

of limestone. The rock is commonly relatively massive (i.e. the component beds are several feet or yards thick) and pure, but wide variations in both stratification and purity are possible.

415. Soil profile characteristics. Soils residual on limestone are as much as 10 to 15 ft thick in some humid portions of the United States, but in others soil may be virtually absent. The thickness is primarily a function of the duration of weathering. In thick soils, the A-horizon is normally from 1 to 3 ft thick, and composed of CL or ML types that are relatively expansive and high in calcium carbonate. The B-horizon is normally 3 to 5 ft thick and composed of CL or CH types that are somewhat more plastic than the A-horizon. The organic content of the surface soils is dependent upon topographic position; the lower slopes of saucer-shaped sinks photograph in slightly darker tones of gray than the upper, both because of a slightly higher organic content and a higher moisture content. Oddly enough, the flat bottoms of sinks also commonly photograph lighter than the lower slopes, chiefly because of slight differences in soil drainage and vegetation types. The resulting "target" appearance, as illustrated in photo a of fig. 39, is striking. The soils are generally sticky and plastic when wet.

416. In arid regions, soil profiles on limestone plains are normally thin and poorly developed, regardless of the length of time they have been exposed to weathering. Banded outcrops defining individual beds are not uncommon.

417. Trafficability and cross-country movement characteristics. Only five limestone plains soils were tested, all in Indiana. Three were on topographically high positions and two on low. The number of samples and their concentration in a single area make it impossible to draw regional generalizations. However, the relatively uniform soil development known to occur on limestones makes it likely that the results of these tests can be applied with some confidence to any limestone plain developed under similar climatic conditions.

418. The soils fell into soil trafficability classes C (CL, 3 samples) and D (ML, 2 samples). The trafficability of both these soils is good during the dry season; they both exhibit RCI's in excess of 300. However, both lose a substantial proportion of their strength when wet, and

the class C soils were the weakest. The RCI's of the CL soil (class C) ranged from 124 to 139 during the wet season, whereas the RCI's of the ML soil (class D) ranged from 158 to 265. Even when wet, these soils remain trafficable for virtually all vehicles.

419. When undisturbed, these soils dry quickly because of rapid internal drainage. However, when the blocky soil structure is partially destroyed by cultivation or heavy traffic, they become relatively impermeable, and therefore dry relatively slowly. In this state they also become sticky, and clinging mud may be a serious trafficability problem. Although firm, these soils will be slippery when the surface is wet.

420. Slopes and vegetation are normally not significant problems. However, the sides of even the saucer-shaped sinks may not be negotiable when the soils are wet. Such areas can normally be easily avoided.

Shale plains

421. Shale surfaces of low relief occur in many parts of the world in virtually all climatic regions. Excellent examples occur in the United States in Indiana, South Dakota, California, and elsewhere. Climate has such a profound effect on shale surfaces that the following description has been subdivided into humid areas, semiarid areas, and arid areas.

422. Regional drainage.

- a. Humid areas. Both the gross and low-order drainage patterns are commonly dendritic or rectangular, but in some places there is a tendency for the low-order stream patterns to be pinnate. The channels are usually quite close together.
- b. Semiarid areas. The gross drainage pattern is basically dendritic with a tendency toward rectangular, parallel, or pinnate types. For example, note that in fig. 40* there is a strongly preferred orientation of trunk channels from upper right toward lower left, especially in the upper half of the photo. The pattern is not quite regular enough to be undeniably trellis, however. The low-order drainage is often distinctly pinnate or trellis. In fig. 40 some low-order patterns appear to be combinations of both. The channels are normally very closely spaced.
- c. Arid areas. The gross drainage pattern is generally basically dendritic, but with very strong tendencies toward trellis, parallel, or rectangular. The low-order drainage

* Overlays for this and subsequent figures are included in the envelope attached to the inside of the back cover of Volume II.

pattern is generally markedly trellis or pinnate. The channels are almost always very closely spaced.

423. Topography.

- a. Humid areas. The cross-sectional shape is rolling on a regional basis, with a notable tendency in any one small area for the ridges and spurs to be subparallel. Slopes are commonly smoothly convex-concave. Local relief usually is less than 400 ft.
- b. Semiarid areas. The cross-sectional shapes are quite variable, the most common being rolling as illustrated in fig. 40. Note that the topographic highs are rounded at the top, but that the small drainageways tend to be V-shaped at the bottom, and the larger drainageways are flat-bottomed with relatively abrupt breaks in slope between the valley sides and the valley floor. Local relief may range up to 500 ft.
- c. Arid areas. The cross-sectional shapes are almost invariably crested, with some tendency toward localized alignments of spurs and ridges. Slopes are generally straight and very steep, reaching as much as 60% in many places.

424. Local erosion.

- a. Humid areas. Gullying is usually intense. The gully shapes are to some degree controlled by the amount of available relief. In regions of very low relief, gullies are normally C type or broadly V type with the upper slopes convexly rounded. In areas of relatively high relief (i.e. about a hundred feet or more), the gullies tend to be markedly V type, differing from those in unconsolidated sands and gravels chiefly in that the gradients in shale tend to be much less. Low-order stream channels generally have flat bottoms, but the longitudinal profiles may be "stepped." Rill and sheet erosion are normally extensive. Landslide scars may be visible in some places.
- b. Semiarid areas. Gullies are usually numerous, as illustrated in fig. 40, but much less so than in arid areas. The rounded upper surfaces of the topographic highs may be scored by many gullies, but the surface is rarely destroyed. As illustrated in fig. 40, the gullies are usually F type with very steep sides.
- c. Arid areas. Gullies are incredibly numerous in most places, and are separated by sharp-crested ridges. The gullies are sharply V type. However, many low-order streams and even the larger gullies commonly have flat bottoms and "stepped" profiles. This condition is produced when joint blocks are swept away by the current during flood, leaving sharply rectangular ledges in the channel.

425. Natural vegetation.

- a. Humid areas. Shale plains are chiefly forested.
- b. Semiarid areas. Vegetation was, and in many places, as in fig. 40, still is grassland. Where trees are present, they normally occur as individual specimens, or as small, open groves along drainageways. Note the small grove in the extreme upper left corner of fig. 40.
- c. Arid areas. Vegetation is very sparse, and may not be visible on airphotos. The impression is one of extreme sterility. However, a few scattered small trees or shrubs may be present along drainageways in some places.

426. Land use and construction practices.

- a. Humid areas. Shale plains are frequently intensively cultivated. In areas of very low relief the field patterns are usually rectangular and essentially independent of topography. However, gullies almost invariably "scallop" the edges of fields in at least a few places. Contour plowing is practiced, resulting in a distinctly linear texture resembling closely spaced and somewhat indistinct contour lines. In areas of relatively high relief, field patterns are markedly affected by topography. They are in general confined to ridgetops and valley bottoms, and are usually very irregular. Contour plowing of ridgetops is common. The ravine sides are forested. Roads are independent of topography in regions of low relief, but tend to follow ridgelines in regions of comparatively high relief. The normal clusters of farm buildings are generally also on the ridgetops. Shales are quarried in many places for ceramic manufacture; quarry walls are normally vertical or nearly so.
- b. Semiarid areas. These areas are not normally used for cultivated crops. However, they may be grazed intensively, and in some places grass may be cut for hay. The peculiar barred texture in the bottom third of fig. 40 may be the indication of this practice. Both roads and railroads tend to follow either ridges or valley floors, as illustrated in fig. 40.
- c. Arid areas. These areas are not normally used for any form of agriculture. Both roads and railroads avoid these regions as much as possible; where it is necessary to cross them, the alignments follow ridges or valley floors.

427. Parent materials. Parent materials are chiefly shales, although thin beds of fine-grained sandstone or limestone are not uncommon. In general, a distinctly rectangular or trellis drainage pattern indicates that the parent material is strongly jointed.

428. Soil profile characteristics.

- a. Humid areas. Soils are rarely more than 2 to 3 ft thick, and are commonly much thinner. The A-horizon is commonly CL or ML type with platy soil structure. The B-horizon is commonly CH with platy fragments of shale embedded. The combination of fine grain size and platy soil structure usually results in a relatively impermeable soil mass. As a result, sheet erosion has in many places removed the fines from upland soils, leaving scarcely more than an accumulation of weathered shale chips mantling the surface. Once saturated, residual shale soils lose moisture slowly; the commonly dark soil color and high moisture content normally result in dark photo tones, although exceptions to this generalization are numerous.
- b. Semiarid areas. Soils are generally relatively thin, rarely reaching more than 12 in. in thickness on the topographic highs. On the slopes they may be even thinner. In many places traces of stratification can be clearly seen as alternating dark and light tones, as illustrated in the area identified by the marginal arrows in fig. 40. On the topographic lows the soils are generally ML or CL types, commonly containing chips of shale. On the topographic highs the soils are usually composed predominantly of shale chips in a matrix of silt. These soils lose moisture slowly, and tend to photograph in relatively uniform dark tones, as illustrated in fig. 40.
- c. Arid areas. Little or no soils are developed in arid areas. Where present, they are chiefly thin accumulations of shale fragments, often almost unweathered.

429. Trafficability and cross-country movement characteristics. No trafficability tests were made on soils developed from shales alone. However, experience from areas in which shale occurs in combination with other rock types suggests the following characteristics:

- a. Humid areas. The soils when wet will probably exhibit RCI's ranging from 30 to 120. During the wet season these soils will probably be untrafficable for category 6 and 7 vehicles, and marginal for categories 2, 3, 4, and 5. The soils will be both sticky and slippery with even small amounts of moisture, so that the valley sides will be largely impassable because of lack of traction. The dense forest in such places would still further reduce freedom of movement. Even during the beginning of dry season, shale plains would probably be difficult to traverse because of the ability of the fine-grained soils to retain water for long periods.
- b. Semiarid areas. The soils are very similar to those in humid regions. However, the obstacles are often quite

different. Vegetation is rarely a problem in semiarid climates, as illustrated by the completely open, grassy slopes shown in fig. 40. However, the often very deep and closely spaced gullies constitute a major cross-country movement obstacle, in many places requiring long and circuitous detours. In addition, the very steep slopes common in semiarid regions, combined with very slippery soils when wet, suggest that in the wet season many slopes would not be negotiable by most military vehicles. Other than during the wet season, these soils will provide sufficient bearing and traction capacities for all vehicles.

- c. Arid areas. The major obstacle to cross-country movement in arid areas is the presence of very large numbers of very deep, V-type gullies. The slopes are usually steeper than negotiable by all military vehicles, even with ideal surface conditions. Add to these steep slopes a very thin covering of noncohesive and very slippery shale chips, and even relatively modest slopes become difficult if not impossible to climb. Even in arid climates the soils in some of the larger valley bottoms would be very difficult to traverse after rain. The RCI's of such soils probably range from 60 to 200.

Sandstone plains

430. Sandstone plains occur widely throughout the world. Excellent examples occur in Indiana, Michigan, Illinois, and elsewhere in the United States.

431. Regional drainage. The gross drainage pattern is generally dendritic. The low-order drainage patterns are very commonly rectangular or trellis types. In some places there is a marked tendency toward a pinnate pattern, as illustrated in fig. 41. The channel spacing is normally relatively wide, as opposed to the closely spaced channels typical of shale plains.

432. Topography. The cross-sectional shape is crested and rolling on a regional basis, and there is a tendency for ridges to be subparallel locally, as illustrated in fig. 41. The valleys, especially those of the low-order streams, generally are characterized by an open U-shape, as illustrated in fig. 41, as opposed to the nearly flat valley bottoms typical of shale surfaces. Slopes of valley bottoms are predominantly concave upward. Local relief may vary from a few tens of feet to 500 ft. Slopes are widely variable, and to some extent are apparently related to local relief; that is, low local relief generally is associated with gentle

slopes. However, even moderate relief, such as that in fig. 41, commonly results in slopes as steep as 36%. Massive (i.e. thick-bedded) sandstones develop vertical escarpments along valley sides in many places, even when local relief is relatively low.

433. Local erosion. In areas of low relief, gullies are rare or absent; they become more numerous as local relief increases. Where present, they are generally V type with steep gradients, as illustrated in fig. 41. To some extent gully development is also controlled by rock hardness. All other things being equal, strongly cemented sandstones are less susceptible of gully erosion than are weakly cemented sandstones. In some places where the residual soils are almost completely without cohesion, eolian erosion may develop deflation basins and sand smears of limited extent. These open scars may then be modified by rill erosion to produce fairly substantial areas of bare soil, which photograph in very light tones. The light spots in the upper right corner of fig. 41 are of this type.

434. Natural vegetation. In humid regions sandstone surfaces of this type were almost without exception forested. The trees were denser than on comparable limestone areas. In semiarid regions sandstone plains are commonly grass-covered, with trees or shrubs in the sheltered and relatively more moist ravines and small valleys.

435. Land use. The cultivation of sandstone plains in humid areas is widely variable, with the proportion of land actually cultivated to a considerable extent dependent upon local relief. In areas of low relief the proportion of cultivation is high, and the fields are chiefly rectangular and independent of topography. In areas of relatively high relief, cultivated fields tend to be confined to ridgetops and valley bottoms, with side slopes either in pasture or in timber. This condition is illustrated in fig. 41. The contrast between the generally light-toned, smooth-textured cultivated fields and dark-toned, botryoidal-textured forest is very striking.

436. Construction practices. In areas of low relief, road alignments tend to be independent of topography, but in areas of moderate to high relief they usually follow either ridgelines or valley lines, as illustrated in fig. 41. Clusters of farm buildings are located either on

the valley floor or on the ridgetops. Sandstones are rarely quarried to the extent of shale or limestone. Where quarries do occur, the faces are generally vertical, and the whole quarry tends to photograph in such light tones that detail is lost.

437. Parent materials. Parent materials are chiefly sandstone, although thin shale or even limestone beds may be intercalated; such occurrences will not normally influence the gross configuration, except to reduce the probability of the formation of vertical escarpments.

438. Soil profile characteristics. All other conditions being equal, sandstones with calcareous cementing material produce thicker residual soils than those with a ferruginous or siliceous cement. As a result, soil profiles on sandstone may range from 1 to 10 ft in thickness, with the deeper soils on the terrain at lower relief. Only two soil samples were taken in residual sandstone soils; both were from Indiana, and both from topographically high sites. These are far too few samples to permit generalization. However, information from other sources suggests that the thin A-horizon is commonly SM or ML type, underlain by slightly more silty or clayey soils of SM, ML, or CL type. The type of soil is undoubtedly dependent to a marked degree upon the relative purity of the parent materials.

439. Residual soils on sandstone are normally well drained internally. Freshly worked fields tend to lose surface moisture very rapidly. This, coupled with the normally light color of the soil, results in a marked tendency for vegetationfree fields to photograph in light tones, as is illustrated by several fields in the lower half of fig. 41.

440. Trafficability and cross-country movement characteristics. The two soil samples examined for trafficability determinations were in soil trafficability class D (ML). These soils exhibit RCI's in excess of 300 during the dry season, indicating excellent trafficability conditions. However, they exhibited RCI's of about 63 and 64 in high topographic positions during the wet season, indicating that they would not be trafficable for category 5, 6, or 7 vehicles, and marginal for category 4 vehicles. In low topographic positions the RCI's may be as low as 45. The relatively steep valley walls, combined with the low RCI's of these soils, suggest that cross-country movement across the "grain" of sandstone plains would

be very difficult if not impossible. Even relative freedom of movement would be confined to ridgetops and valley floors. The normally relatively dense tree growth on valley sides and in ravines would be an additional inhibition in many places.

Limestone-shale plains

441. These surfaces are composed of interbedded limestones and shales. They may exhibit some of the characteristics of both pure limestone and pure shale surfaces, but the combination of the two dissimilar rocks usually introduces characteristics that are typical of neither.

442. Regional drainage. The gross drainage pattern is predominantly dendritic. The low-order pattern is also usually dendritic, but not uncommonly these areas exhibit a slight tendency to develop a pinnate or rectangular pattern. For example, the low-order drainage patterns indicated by marginal arrows A in fig. 42 are basically dendritic, but with a marked tendency toward the pinnate form. There may also be areas of swallow-hole drainage, although these are rare.

443. Topography. The cross-sectional shape is mostly blocky, as illustrated in fig. 42. Note that the upper surface of the blocky topographic highs is a relatively subdued combination of crested and rolling. It is not rare for the topographic highs to exhibit a small, and generally somewhat incomplete escarpment near or at the top. In many areas, such as that illustrated in fig. 42, this escarpment is so subdued that the impression is only one of markedly concave slopes on the highs. The normally smooth slopes which usually develop in shale may be broken at one or more elevations by "scarplets," each of which normally represents a thin limestone bed. The bottoms of the low-order drainageways, such as those near the middle of fig. 42, are normally V-shaped, while those of major trunk streams are generally flat-bottomed, with relatively sharp breaks in slope between valley floor and valley sides. This feature is illustrated near the bottom of fig. 42. In some places the upper surface of the topographic highs may be basined, but this condition is rare.

444. Local erosion. Gullies are normally of two distinct types. Those on the upper surfaces of the topographic highs are generally C type, or may be entirely absent. Note that in fig. 42 the first-order streams which begin on the upper surface of the highs originate in open, rounded

swales, generally without a scour channel. The gullies on the sides of the topographic highs are usually relatively open V type, as illustrated by those identified by marginal arrows B in fig. 42. In many cases their longitudinal profile is "stepped" because of alternating hard and soft strata; however, the "steps" are often so small that their relief cannot be stereoscopically detected, as illustrated by those identified by marginal arrows C in fig. 42. Evidences of sheet and rill erosion are usually common; note the light-toned areas on almost every slope in fig. 42.

445. Natural vegetation. Natural vegetation in a humid area generally consisted of dense forest. Note that the uncleared slopes in fig. 42 are covered by very dense tree cover. The species assemblages on the upper surfaces of the topographic highs were (and still are in some places) different than on the side slopes, but this is ordinarily impossible to detect on an airphoto.

446. Land use. There is usually a distinct topographic control of field shapes, as illustrated in fig. 42. Even in areas of relatively low relief cultivated fields tend to be confined to the tops of the uplands and the flat valley floors. Hillsides are commonly used for grazing, in which case they are normally grass-covered with scattered shrubs, or else used for timber as illustrated in fig. 42.

447. Construction practices. Road alignments are not obviously controlled by topography in areas where relief is low, although they are usually slightly sinuous as the result of alignments selected to take advantage of minor valleys to ease the grade going into and out of large valleys. In areas of high relief, such as that illustrated in fig. 42, the roads are chiefly on hilltops and valley bottoms. There is normally little if any quarrying, because the thin limestone and shale beds typical of this landscape are usually not exploited for industrial purposes.

448. Parent materials. This landscape normally develops in a rock sequence that is largely shale, with only occasional thin beds of limestone. When the limestone beds become numerous enough or individually thick enough to dominate the rock column, the entire rock mass may react to erosion as if it were entirely limestone. No clean line of distinction separates limestone, limestone-shale, and shale plains; the component rocks

can occur in any possible combination. The parent materials of flat-topped uplands, such as those illustrated in fig. 42, are almost invariably limestone, while the parent materials of the side slopes of the topographic highs are chiefly shale.

449. Soil profile characteristics. Soils are chiefly of two basic types: those residual on the limestones and those which are formed by components of both limestones and shales. The depth of weathering is similar to that of limestone or shale when found alone. Of the seven soils classified, one was CH, four were CL (two from topographically high sites and two from a low site), one was ML, and one OH. Physical soil properties are slightly more variable than those of soils found on either shales or limestones alone.

450. Trafficability and cross-country movement characteristics. The soils of this landscape fell into three soil trafficability classes: B (CH), C (CL), and D (ML and OH). On the basis of available data, class B high-site soils would be trafficable to all vehicles but slipperiness and stickiness would be a deterrent. The high-site class C soils were slightly weaker than the low sites. The ranges in RCI's for the high and low sites were 66 to 111, indicating that the soil strengths would be adequate for vehicle categories 1 to 4 with limited going for some vehicles in categories 5 and 6. For the two class D soils, one at a low site and one at a high, the RCI's were 53 and 64, respectively, which are adequate only for vehicle categories 1, 2, and 3.

451. It is probable that all soils in this type of landscape are entirely trafficable when dry. In addition to the trafficability properties of the soils during the wet season, the valley walls probably offer serious obstacles to cross-country movement. The slopes are generally somewhat steeper than for pure shale at comparable relief, and the terraces formed by the outcroppings of resistant limestone are virtually impossible for vehicles of any type to negotiate in many places. In many areas in humid regions the combination of slope and closely spaced trees will make the slopes difficult if not impossible to negotiate.

Sandstone-shale plains

452. These surfaces are composed of interbedded sandstones and shales. They incorporate some of the characteristics of both pure

sandstone and pure shale surfaces, but the combination of the two dissimilar rocks introduces characteristics that are typical of neither. This surface cannot normally be differentiated from shale surfaces unless the interbedded sandstones are appreciably more resistant to erosion than the shales.

453. Regional drainage. Gross drainage patterns are normally dendritic and faintly rectangular. Low-order patterns are commonly distinctly rectangular, trellis, or pinnate but in many places they are dendritic. The tendency toward rectangular patterns occurs when the sandstones are thoroughly jointed, usually in two directions at approximately right angles.

454. Topography. The cross-sectional shapes are generally blocky if the surface stratum is resistant sandstone, whereas a crested form normally develops when the resistant sandstone is covered with a less resistant rock. In the latter case, the landscape may develop a very crudely "layered" or "terraced" appearance, with somewhat flattened hilltops or ridgetops at several levels, each level representing a stratum of resistant rock. This is the situation exhibited in fig. 43. The sandstone-shale plains cannot usually be differentiated from sandstone plains in areas of low relief; therefore, the sandstone-shale combination can only be recognized in areas where the relief is in excess of about 75 ft.

455. Local erosion. Sandstone-shale parent materials are as susceptible of gullying as shale alone. Very commonly the gullies are distinctly two-layered. This is excellently illustrated by many of the gullies in fig. 43. Note the broad, open V type of the upper walls, and the very nearly vertical lower walls forming a sort of "inner gorge," as indicated by the marginal arrows in fig. 43. The steep inner parts are generally incised in sandstone; the broad upper portions are developing in shale or in residual soil.

456. Natural vegetation. The vegetation on this landscape was chiefly forest in humid climates, grass in semiarid climates, and desert scrub in arid climates.

457. Land use. Field patterns are strongly controlled by topography. In general, the hills or ridgetops and the valley floors are cultivated, and the side slopes allowed to remain in grass and timber. The

abundant gullying illustrated in fig. 43 is at least in part the result of violating this practice. Contour plowing is common on the upland fields in many places.

458. Construction practices. Roads follow ridgelines or valley bottoms, as illustrated in fig. 43. There is rarely evidence of quarrying in this type of landscape, but strip mining is practiced in regions where coal is present.

459. Parent materials. These landscapes normally develop in a rock sequence that is largely shale, with relatively thin beds of sandstone. When the sandstone beds become numerous enough or individually thick enough to dominate the rock column, the entire rock mass tends to react to erosion like a pure sandstone. The parent materials of this type, therefore, are dominantly shale with minor amounts of sandstone.

460. Soil profile characteristics. Soil profiles are similar to those developed on shale alone. However, the soils of low topographic positions tend to be slightly sandier than those in comparable positions in purely shale landscapes. Only two samples from sandstone-shale plains were examined, too few to permit drawing of valid generalizations. The one sample from a high topographic site was a CL soil type. However, the low site was classified as ML.

461. The internal drainage of these soils is relatively poor. When bare soils are exposed, as in the side of a ravine or gully, the surface fraction of an inch dries very rapidly by evaporation. As a result, ravine scars tend to stand out sharply as very light-toned spots against the predominantly dark tones of the undisturbed and vegetation-covered soils. This property is strikingly illustrated in fig. 43.

462. Trafficability and cross-country movement characteristics. The soils in this landscape fell into soil trafficability classes C (CL) and D (ML). The class C soil, from a high topographic site, exhibited an RCI of 82 during the wet season. This soil is trafficable to all vehicle categories except 7 with marginal trafficability for category 6 vehicles. The low site consisted of an ML soil (class D) which exhibited an RCI of only 26 during the wet season. Thus, this soil is untrafficable for category 2 through 7 vehicles, and marginal for category 1. Furthermore, the fine-grained soils will drain so slowly that conditions would probably

remain poor for some time after a soaking rain even in the dry season.

463. The relatively steep valley slopes and the numerous ravines would further impede cross-country movement. The soils become slippery when wet, so that even a minor rain would probably make many of the slopes unclimbable. The timberclad valley sides would add still another inhibition to cross-country movement.

Sandstone-shale-limestone plains

464. Many rock sequences consist of complexly interbedded sandstones, shales, and limestones. In general, the landscapes which develop on such sequences are complex combinations of the forms typical of all three types, but they are usually so blurred by their interdependence that it is difficult or impossible to determine where one rock type begins and another ends.

465. Regional drainage. The drainage patterns are normally typical of either shale or sandstone, since the drainage features typical of limestone are rarely developed. As a result, the gross drainage pattern is normally either dendritic or rectangular, and commonly a combination of both. For example, note that the gross drainage pattern in fig. 44 is basically dendritic, but with a marked angularity that suggests the rectangular type. The low-order drainage pattern is mostly dendritic, as illustrated in the lower third of fig. 44. In a few cases channels may vanish or fade out, as illustrated in the upper right corner of fig. 44, suggesting a very local occurrence of swallow-hole drainage.

466. Topography. The surface configurations of this landscape are normally complex, as illustrated in fig. 44. The landscapes are often "stepped"; the general impression is one of blocky cross-sectional shapes, but very commonly isolated crested or blocky masses will rise above the general upper surface of the topographic highs. These features are well illustrated in fig. 44; note the crested topographic high at the point identified by marginal arrows A. Valley cross sections are normally widely variable, ranging from broad, open U shapes to relatively sharp V shapes, both of which, plus several intermediate forms, are discernible in fig. 44. Widely variable valley cross sections are a primary recognition feature of this landscape type.

467. Local erosion. Like all other topographic expressions of this

landscape type, the gullies are widely variable. Those which form in predominantly shale parent materials are normally C type, as illustrated by marginal arrows B in fig. 44, while those in predominantly sandstone materials tend to be V type, such as those indicated by marginal arrows C in fig. 44. Sheet and rill erosion are common, often appearing as a light-toned fringe or zone around C-type gullies, as illustrated by many of the gullies in fig. 44.

468. Natural vegetation. In humid areas natural vegetation was normally relatively dense forest. Growth tended to be more dense on shales and sandstones than on limestones, but this relation is often obscured in second-growth timber.

469. Land use. Field shapes are strongly influenced by the amount of local relief. Where the relief is considerable, as in fig. 44, fields tend to be somewhat irregular, and confined to the upper surface of the topographic highs and the valley floors, with the valley sides in timber or rough pasture. In areas of low local relief, the field patterns tend to be rectangular and independent of topography.

470. Construction practices. In regions of low relief the roads tend to be independent of topography, but where relief is relatively high, as in fig. 44, the roads tend to be sinuous and to follow either ridgelines or valley bottoms. Since the ridges are usually irregular and discontinuous, road alignments not uncommonly are marked by many cuts (as at the point marked by marginal arrows D in fig. 44) and fills. Clusters of farm buildings tend to be on the ridgetops. Quarries are numerous in many places, but none are illustrated in fig. 44.

471. Parent materials. The parent materials may be any combination of interstratified limestone, shale, and sandstone. In such sequences the individual rock types are often impure; thus, the limestones tend to be shaly or even sandy, and the sandstones are often shaly or limy. These gradational types make it even more difficult to determine either the precise sequence or the exact type of rock underlying any given soil, because the resulting topographic expressions also tend to be gradational. The most common sequences are, from top to bottom, limestone, shale, and sandstone, or the reverse. However, there are many exceptions to this generalization.

472. Soil profile characteristics. General statements concerning the characteristics of soils from topographically high or low sites are impossible, because of the widely variable rock types from which they may have developed. Each must be interpreted in terms of the probable sequence in the area being studied, rather than in terms of the landscape type as a whole. For example, on the basis of topographic expression, local drainage characteristics, and gully form, the soils on the upper surface of the blocky topographic highs in fig. 44 are probably derived chiefly from shale, and will therefore strongly resemble those on shale plains. The soils in the topographic lows are probably complex soils derived from all three major rock types (i.e. sandstone, shale, and limestone).

473. Five soil samples were examined from landscapes of this type. Of these, three were taken from topographically high sites and two from low positions. Two soils from the high sites were classified as ML, while one was classified as CL. Both of the soils in low positions were of CL type. The soils tested were remarkably homogeneous with depth; none changed classification type in the upper 18 in.

474. Trafficability and cross-country movement characteristics. Soils of this landscape type fell into soil trafficability classes C (CL) and D (ML). The class C soils are highly variable in trafficability properties during the wet season. The RCI's of the three soils in this class ranged from 59 to 165. Thus, trafficability within this single soil type ranges from poor to very good. It is probable that all soils in this class would be poor (in regard to trafficability) at high moisture contents. The class D soils are closely similar to each other in texture as well as in trafficability properties. One exhibited an RCI of 145, while the other had an RCI of 155. Both these soils are, however, trafficable, and would probably remain so all year round.

475. Cross-country movement would be seriously inhibited in areas of considerable local relief (such as the area illustrated in fig. 44) by steep slopes, terracettes, and closely spaced trees on the valley sides. In general, this landscape would be extremely difficult to traverse in the wet season in humid climates, but would be negotiable for tracked and all-wheel-drive vehicles during the dry season.

Landscapes of High Relief in Horizontally
Stratified, Sedimentary Rocks

476. The distinction between surfaces of high relief and low relief, as derived from horizontally stratified rocks, is purely an arbitrary one. In this report, the distinction is made on the basis of local relief; a surface having in excess of 500 ft of local relief is defined as having high relief. In general, the resulting landscapes are those normally identified as plateaus. It is evident that these surfaces of high relief, if developed under climatic regimes and from rock types similar to those of low relief, will have many factors in common with those of low relief. However, the fact of high relief often results in certain combinations of properties that are different in both kind and degree from those of surfaces of low relief. Accordingly, these surfaces are treated independently in this report.

Limestone plateaus

477. Surfaces of this type are found in many parts of the world. Well-known examples include the Karst region of Yugoslavia, northern Indochina, and parts of Puerto Rico. In the United States, such areas are found in Arizona, Kentucky, Tennessee, Missouri, and elsewhere.

478. Regional drainage. The gross drainage pattern is often an extreme form of swallow-hole type. However, through-flowing streams are frequent in many places; these rarely have obvious tributaries. The large basins (i.e. sinks) commonly have streams flowing through from end to end, but in many instances such channels will have no tributaries; the stream emerges full-blown from beneath the bounding wall at one end, and vanishes beneath the wall at the opposite end. The low-order drainage consists chiefly of short, predominantly dendritic systems leading to sinks. Scour channels tend to be more prevalent than in limestone plains.

479. Topography. Surface configurations in this type are incredibly varied, but the cross-sectional shapes are chiefly blocky and crested. These forms may occur in virtually any combination. In addition, varying degrees of alignments of topographic features may also occur. The sinks in this landscape are commonly, but not invariably, bowl- or cylinder-shaped. To achieve the degree of relief required for this landscape (more than

500 ft), some extensive basins or even valleys must be present. These are almost invariably nearly flat-bottomed, with very steep to vertical walls. Such large basins or valleys are commonly irregularly elongate, and in many places are at least crudely aligned. The large sinks may be so enlarged that only discontinuous ridges or pinnacles (often called "haystacks"), almost invariably steep-sided, may remain of the original limestone. Because massive limestones often overlie shales, the end member of the evolutionary development of the landscape type is commonly a shale plain with limestone remnants.

480. Local erosion. Gullies are rare. When present on the uplands they are generally C type, but may be a very open V type in some places. Valley or basin walls are rarely marked by gullies. Such walls commonly retreat by sapping at the base; as a result, rockfalls composed of large angular blocks are not uncommon at the bases of walls, or even in the bottom of steep-sided basins.

481. Natural vegetation. Natural vegetation is controlled by climatic regime. However, all other things being equal, the vegetation on the uplands of limestone regions of high relief is normally smaller and less dense than the climate alone would suggest. Some limestone regimes of this type are, in fact, almost desert-like. The condition of aridity is the result of the abnormally rapid internal drainage through the normally solution channel-riddled limestones. The contrast of arid uplands and verdant well-watered basins and valleys is often striking. In the eastern United States the original vegetation was commonly a relatively open forest of small stature with many small enclaves of prairie.

482. Land use. In the eastern United States, limestone regions of this type are cultivated or used for grazing. In either case, the field patterns tend to be rectangular or polygonal, with the pattern interrupted by sinks. The bottoms of some of the larger basins may be cultivated. Valley sides and sinks are commonly wooded. In semiarid and arid regions limestone topographic highs are rarely used except for range grazing, and no field pattern of any persistence is normally present. However, the bottoms of basins and through-flowing valleys are generally cultivated and irrigated.

483. Construction practices. Roads on uplands are somewhat sinuous,

their alignments having been selected to avoid basins. Road alignments are markedly deflected, because of the necessity to detour to achieve a climbable grade up the precipitous wall. Quarries are common in many places. Straight, vertical working faces and smooth "steps" imply relatively massive, sound rock being quarried for building stone; irregular faces imply stone used for construction aggregates or for industrial purposes.

484. Parent material. This parent material is massive limestone, but degree of purity, hardness, and other properties may be widely variable. The parent material in the bottom of large basins or valleys is usually unconsolidated alluvial material.

485. Soil profile characteristics. Soil profiles in arid and semi-arid regions are thin and poorly developed. The soils are stony, with patches of bare rock showing through. This character is revealed on photographs as irregular, but relatively sharply defined splotches of light photo tones against the somewhat darker soils. In humid regions such as the eastern United States the soils may be as much as 15 ft thick, although they are generally much thinner. The A-horizon is somewhat more plastic than the B-horizon, and is commonly either of CL or CH type.

486. Soils in the large basins and valleys are at least partly alluvial in origin or are derived from the shale or other rock underlying the limestone, and may therefore not be related to the regional soils. Soils on the escarpments bounding the basins and valleys are thin and discontinuous.

487. Trafficability and cross-country movement characteristics. All ten soils tested for this report were from Kentucky, Tennessee, and Missouri. Of these, five were on topographically high sites and five on low sites. All ten sites were of CL type (soil trafficability class C). There is no apparent correlation between soil strength, as measured by the RCI, and topographic position. The RCI of the low sites during the wet season ranged from 84 to 192 and that for the high sites ranged from 84 to 200.

488. From these data it appears that limestone regions would be readily trafficable all year round for all vehicle categories, except that some areas will be marginal for vehicle categories 6 and 7. These areas would be easily trafficable in the dry season.

489. Cross-country movement across the escarpments bounding valleys or large basins would be impossible without extensive engineering support because of the very steep, and even vertical slopes. Movement on the uplands would be easy, even where forested, because the trees are generally relatively widely spaced.

Sandstone plateaus

490. Surfaces of this type are found in the United States in Kentucky, Wyoming, Colorado, Arizona, and elsewhere.

491. Regional drainage. The gross drainage pattern is commonly dendritic, but there is often a tendency for valley trends to be abnormally straight in some reaches. Where channels are meandering, as in fig. 45, there are frequently at least two preferred directions for the reaches. The crossed arrows at the lower left of fig. 45 indicate the dominant orientations of channel reaches. Where such orientations are apparent, the low-order drainage is usually similarly oriented, as illustrated especially in the bottom half of fig. 45. However, in spite of the angularity of the trunk stream channels, the low-order systems as a whole tend to be dendritic. Normally the tendency toward angularity or rectangular drainage types is more apparent in arid regions than in humid regions.

492. Topography. The cross-sectional shape is mainly blocky, as illustrated in fig. 45. Note that even the narrow wall-like spur at the point indicated by the marginal arrows labeled A in fig. 45 is flat-topped. Crested surfaces do occur, chiefly in areas where the parent material is thin-bedded, and where local relief is very great. Valley cross sections in humid regions are usually very open U or V shape, as opposed to the nearly flat valley floors common in limestone and shale. In arid regions the sides of valleys generally consist of vertical portions separated by relatively flat, terrace-like "benches," thus giving the whole landscape a distinct, layered appearance. Note that this characteristic is evident even in low-order valleys, such as that indicated by marginal arrows B in fig. 45. This feature is usually much less obvious in humid climates, but normally some trace of it can be found. Especially in arid regions the longitudinal profiles of low-order streams are commonly interrupted by falls or rapids; the site of a fall is often marked by an amphitheater-like reentrant with vertical walls, as illustrated by the example

identified by marginal arrows C in fig. 45. Evidence of rockfalls is rare, and in most places absent.

493. Local erosion. In areas of great local relief, the soils are often too thin to permit the formation of true gullies. Where they have developed, they are chiefly V type with steep gradients. In some places in arid regions the wind removes sand grains as rapidly as they weather free, leaving bare rock surfaces on the topographic highs, and dunes on the lows.

494. Natural vegetation. In humid regions sandstone plateaus are usually densely forested. In arid regions, they are normally covered with widely spaced desert shrubs or small trees, as illustrated in fig. 45. In such areas, zones of denser growth often are found around the bases of topographic highs, where moisture tends to emerge after percolating through the rock masses above. This feature is illustrated by examples in the upper right corner and lower middle of fig. 45. This feature is usually less obvious in humid regions, but traces of it can usually be found.

495. Land use. Sandstone surfaces are generally not intensively cultivated, chiefly because the soils tend to be relatively infertile. Large tracts still remain forested in the eastern United States. Where cultivated, fields are confined almost entirely to valley floors and the upper surfaces of topographic highs. Fields usually terminate sharply at the edges of the valley walls, which are almost always forested.

496. Construction practices. Roads and railroads are generally confined to either valley floors or the upper surfaces of topographic highs. Alignments are normally very sinuous, and long detours are required to achieve a reasonable grade out of the topographic lows. Quarries are rare in most places, but where present they tend to be vertical-walled, and their floors and sides tend to produce very light photo tones. In some photos the quarry area is so overexposed that detail is lost.

497. Parent materials. Sandstones are highly variable in resistance to erosion, in mineralogy, and in thickness of bedding. Although many exceptions occur, the following generalizations can be made:

- a. The greater the resistance to erosion the steeper the valley walls.
- b. Ferruginous or siliceous cementing materials generally result in steeper valley walls than do calcareous materials.

- c. The more massive the sandstone (i.e. the thicker the component beds) the steeper the valley walls.
- d. Pure sandstones (i.e. those without substantial proportions of fines) are commonly more resistant to erosion than impure sandstones.

498. Soil profile characteristics. Residual soils in sandstones even in humid regions are commonly relatively thin, rarely exceeding 4 or 5 ft. The A-horizon on the topographic highs is usually very thin, and is normally either SM or CL type. This horizon is underlain in most places by a slightly siltier and more plastic B-horizon from 1 to 4 ft thick; this horizon is so similar texturally to the A-horizon that it also classifies as either SM or CL. Soils on valley sides are generally thin and discontinuous.

499. In arid and semiarid regions the soils on the topographic highs are thin and discontinuous. In some places the soil consists almost wholly of rock chips and fragments, the sand grains which have weathered free having been removed by the wind. Extensive areas of this surface type occur in African and Asiatic deserts, though they are uncommon in the United States.

500. Trafficability and cross-country movement characteristics. Only four soils were tested in sandstone plateaus. A topographically high site and a low site were tested in Kentucky, and a high and low site in Wyoming. The Kentucky soils fell into soil trafficability class C (CL), while that of Wyoming was class D (SM) for the low site and class C (CL) for the high site. These are far too few samples to allow generalizations to be made.

501. The Kentucky soils (CL) exhibited an RCI range of 123 to 170 during the wet season. These soils would be trafficable all year round for all vehicle categories. The Wyoming soils were very dry when tested, and exhibited an RCI in excess of 300, indicating excellent trafficability.

502. Cross-country movement across the valley sides in humid regions would be very difficult to impossible without extensive engineer effort, because of the very steep valley sides. In arid regions the vertical or near-vertical sides would prohibit movement except along topographic highs and valley floors.

Sandstone-shale plateaus

503. Surfaces of this type are found in the United States in the Cumberland Plateau and in extensive areas in Wyoming, Arizona, and elsewhere.

504. Regional drainage. The gross drainage pattern is normally either dendritic or rectangular, and occasionally a combination of both. Other patterns also occur; for example, the gross drainage pattern illustrated in fig. 46 is probably the parallel type. Low-order drainage patterns are often distinctly rectangular, as illustrated by the drainage system in the center of fig. 46.

505. Topography. The cross-sectional shape is blocky or crested. The valley sides are distinctly concave upward, and are often "benched." Each bench, a form of terrace, is normally caused by the resistance to erosion of an interbedded stratum of sandstone. This feature is illustrated in fig. 46; the benches can be seen on the slopes of the large mesa in the center of the photo. Valley walls are rarely vertical, except for the edges of the benches; they are very steep, frequently reaching slopes of about 36%, and in rare instances even 60%. In humid climates the valley floors are nearly flat, but in arid regions they tend to be broadly V-shaped.

506. Local erosion. Gullies are abundant. They are generally sharply V type, and have "steps" in their profiles, each step representing a resistant rock stratum. They drain valley walls in an almost endless succession of parallel channels which join the trunk channel at nearly right angles. Evidences of sheet and rill erosion are common.

507. Natural vegetation. In humid climates this landscape is normally forested. In arid climates it is generally vegetated in a peculiar way. The sandstone strata commonly store at least a portion of incident water, where it is readily available to plants. The relatively impermeable shales do not permit infiltration, storage, or percolation, and therefore tend to be barren. As a result, it is not uncommon to find the situation illustrated in fig. 46, in which each sandstone stratum is marked by a dark band of vegetation, separated by barren strips representing the shales. Such natural contouring occurs even in humid regions, where it is not

unusual to find rows of shrubs or trees marking sandstone outcrops on otherwise grassy hillsides.

508. Land use. In humid regions, cultivation is confined almost exclusively to flat-topped uplands and the valley floors, with the slopes used for grazing or left in forest. Fields are irregular, terminating sharply at the edge of the cap rock, or valley wall.

509. Construction practices. Road alignments tend to be slightly more independent of topography than in sandstone or limestone landscapes of similar relief, chiefly because of somewhat gentler slopes.

510. Parent materials. Parent materials are interbedded shales and sandstones, with the shales occupying the major portion of the rock column. Shales are relatively brightly colored, and rarely occur in thick sequences without some color changes. These changes are normally clearly visible as alternating dark and light streaks on aerial photographs. In arid or semi-arid regions these bands are often strikingly conspicuous, as illustrated in fig. 46. They are sometimes visible, though much less distinctly, even in humid regions if the slopes are not masked by vegetation.

511. Flat-topped uplands as in fig. 46 normally imply the presence of a sandstone cap rock. Crested topographic highs imply that at least the upper portion of the uplands is shale. For example, the small crested ridge which projects above the flat surface of the central mesa at its upper right extremity in fig. 46 is probably a remnant of a shale sequence lying above the now-prominent sandstone cap rock of the remainder of the topographic high.

512. Soil profile characteristics. On flat-topped topographic highs the soils are chiefly residual from sandstone. On slopes the soils are usually very thin and poorly developed. On lower and gentler slopes, and on valley bottoms, the soil profiles may reach several feet in thickness. They are generally similar to those derived from shale alone, but show a slight tendency to be coarser grained due to the contributions of the interbedded sandstone.

513. The soils are normally relatively homogeneous insofar as grain size is concerned; changes in classification rarely occur in the upper 18 in., although there is a slight (and not necessarily consistent) increase in plasticity with depth. The soils are generally of either CL or ML type.

514. Trafficability and cross-country movement characteristics. The ten soils classified for this report fell into soil trafficability classes A (SP), C (CL), and D (ML). There is possibly a slight correlation between class and topographic position; five class C soils and one class D soil occurred on high sites, while one class A soil, one class C soil, and two class D soils occurred on low sites. The class C soils in all climates for the high sites exhibited RCI's greater than 100 during the wet season, indicating that these soils would be trafficable for all vehicle categories all year round. The RCI range was from 116 to 300+. The class D soil for the high site exhibited an RCI of about 81 during the wet season which would be trafficable to all vehicles except vehicles in category 7 and marginal for some category 6 vehicles. For the low sites the CI for the class A soil was 118. The RCI for the class C soil was 104, and the RCI for the class D soils ranged from 83 to 139. These soils would be trafficable for all vehicle categories with the exception of some marginal going in class D soils for vehicle categories 6 and 7.

515. The fine-grained soils of this landscape become slippery when wet. Thus, even the comparatively gentle slopes will probably not be negotiable during the wet season because of lack of traction. The terracettes (or benches) caused by strata of sandstone will be insurmountable obstacles to vehicles of all types in many places. In humid regions the relatively dense growth of trees on the side slopes would be an additional inhibition to movement.

Landscapes in Inclined Stratified, Sedimentary Rocks

516. Stratified rocks which are folded or otherwise displaced such that the bedding planes are no longer horizontal result in erosional landscapes quite unlike those resulting from the erosion of rocks in which the beds are horizontal. There is also a qualitative difference in configuration and properties of landscapes in inclined stratified rocks, depending upon relief; low relief implies a certain spectrum of associated conditions and properties, and high relief implies a somewhat different spectrum. Surfaces of low relief in inclined rocks are fairly common, but they are not discussed in this report. The landscapes herein discussed range in

local relief from a minimum of about 200 ft to a maximum of several thousand.

517. Qualitative differences in landscapes also result from variations in rock type. For this reason, the following discussion is divided into segments on the basis of the rock type, or combination of rock types. Qualitative differences in landscape are also controlled by the degree to which the rock strata are inclined. A dip of 5 degrees tends to produce a notably different configuration, and a different spectrum of properties, than a dip of 90 degrees. For this report, however, virtually all tests were conducted in landscapes composed of rocks dipped from a minimum of about 15 to a maximum of about 70 degrees. Even within this range some striking differences develop. Where such differences are pertinent to a specific rock type, they are mentioned in the text. Some of these differences, however, occur more or less independent of rock type. The following generalizations can be made, although exceptions are numerous.

- a. The ridges formed in gently dipping beds are asymmetrical, and become more asymmetrical as the dip increases. Ridges formed of vertical beds are rarely asymmetrical.
- b. The more resistant the rock to erosion the steeper the slopes of the ridges. In gently dipping rocks, this applies only to the so-called escarpment face of the asymmetrical ridge.
- c. The thinner the beds the less the resistance to erosion.
- d. The closer the jointing the less the resistance to erosion.
- e. Regional drainage patterns are almost all trellis on a regional basis. In regions where the angle of dip is relatively small, the drainage patterns in any one valley are almost invariably distinctly asymmetric. This condition persists in some degree even when the dip becomes relatively steep, as illustrated in fig. 47.

Limestone hills or mountains

518. Landscapes of this type are common in many parts of the United States. Those described in this report are chiefly in the so-called "folded Appalachians." The inclined bedding in this region is the result of relatively intense, but nearly symmetrical folding of a thick sequence of bedded sedimentary rocks.

519. Regional drainage. The gross drainage pattern is commonly of

the trellis type, usually more or less disturbed, so that the angles of junction of stream segments are less than 90 degrees, as illustrated in fig. 47. The low-order drainage patterns are trellis or parallel, with the trunk channel parallel to the strike of the rock folds. Note that the channel indicated by marginal arrows B in fig. 47 is almost straight, and that the first-order tributaries, which are very poorly developed, join at almost right angles to form a very crude trellis pattern. There are usually at least a few examples of swallow-hole drainage, with the sinks normally somewhat elongated in the direction of strike of the rock folds, or in the direction of a dominant joint set, as illustrated by the example indicated by marginal arrows A in fig. 47. Channels tend to fade out into swales with no visible scour channels, as illustrated by many of the low-order streams in fig. 47.

520. Topography. The cross-sectional shape is generally rolling or crested in humid climates. Note that the topographic highs in fig. 47 tend to be crested, but that the tops of some of them are smoothly rounded. The topographic highs are generally ridges with relatively smooth crests, as illustrated in the bottom half of fig. 47. Very often there will be two preferred orientations, usually but not invariably at close to right angles. Note that in fig. 47 the preferred orientations, as indicated by the crossed arrows below the photo, are far from being at right angles. There are usually at least a few areas of basined topography, as illustrated by the area indicated by marginal arrows A in fig. 47. Basins rarely form on the sides of topographic highs, because the opportunities for surface drainage are too great. Slopes rarely exceed 35% as a whole, although steep and even vertical segments do occur in some places.

521. In arid regions the cross-sectional shape is usually crested, with precipitous slopes. The crests and slopes are often irregular and "broken" in appearance.

522. Local erosion. The clayey residual soils that develop on limestones are not very susceptible of gully erosion. Where slopes are gentle, as along wide valley bottoms, the few gullies that do develop are C type or very broadly V type. On the steep ridge sides they tend to be steep V type despite the soil type, as illustrated by those indicated by marginal arrows C in fig. 47. In such places the profiles are often "stepped," especially

when the limestone is composed of beds of different resistance to erosion. Note that the major gully indicated by marginal arrows C has a highly irregular longitudinal profile. Rockfalls may occur at the bases of the occasional very steep or vertical slopes.

523. Natural vegetation. Limestones in humid areas were commonly forested. In some places such forests were characterized by "openings"; these are treeless areas in which soil is absent or so thin that forest growth is impossible. Such openings are visible on photos as smooth-textured spots of light gray surrounded by the dark botryoidal texture of the forest. Such openings occur most frequently along ridgetops or on very steep slopes. In arid regions limestones are generally very sparsely vegetated, and the plants are so small that they may be undetectable on photos.

524. Land use. Land use is controlled by both climate and slope. On markedly asymmetrical ridges (i.e. where the beds are only gently dipping), the dip slopes may be cultivated in humid climates. Orchards are relatively common when the climate is appropriate. In such places contour plowing is frequently practiced. Where slopes are so steep that cultivation is impracticable, the ridges are normally forested or in scrub, as illustrated by many of the ridges in fig. 47. Almost invariably the relatively flat topographic lows are cultivated.

525. Construction practices. Roads tend to follow valley floors as much as possible, as illustrated in fig. 47. They normally cross the ridges at water or wind gaps. Quarries occur in some places. Straight, stepped working faces imply massive, hard rock. Irregular working faces imply material that is used as aggregate or for industrial purposes, and no useful deductions as to the precise nature of the rock can ordinarily be made.

526. Parent materials. The limestones forming this type of surface are of widely differing properties in various places. It is relatively rare to find an entire landscape composed of limestone; almost invariably it will be associated with varying amounts of interbedded shales, sandstones, or both.

527. Soil profile characteristics. The thickness of the soil profile is a function of several factors, probably the most important being climate and terrain. In general, the steeper the slope the thinner the

soil profile, and the wetter the climate the thicker the profile. Thus, in arid regions, where steep slopes and dry climates coexist, soil profiles are normally very thin or even completely absent. In the humid eastern United States, the soil profiles vary from a few inches on the steeper slopes to several feet in the flat valley floors.

528. Limestone soils, especially where uncultivated, commonly have spheroidal or blocky structures. As a result of such structures, these soils normally have excellent internal drainage, and dry rapidly. They tend to photograph in light and relatively uniform tones of gray when vegetation-covered, as illustrated in fig. 47. When cultivated, these soils may lose their structure and become relatively impermeable, in which case they may retain soil moisture for quite long periods of time. However, freshly worked soils often photograph in startlingly light tones, as illustrated by the field indicated by marginal arrows D in fig. 47, because the surface tends to dry quickly even though the soil a fraction of an inch below the surface may be quite moist.

529. Trafficability and cross-country movement characteristics. Of the four soils tested in this landscape type, three were classified as CL (soil trafficability class C) and one as CH (class B). There is no apparent relation between soils type or class and topographic position. The class B soil (high topographic site) exhibited an RCI in excess of 300 during the wet season. The class C soils (CL, one high and two low sites) exhibited RCI's ranging from 256+ to more than 300 in the same layer during the wet season. All four soils would be readily trafficable all year round.

530. Cross-country movement would be inhibited or stopped by steep ridge slopes where local relief is high. Dense forest or brush on the slopes would be an additional handicap. Movement across the "grain" of landscapes of this type would be difficult even in areas of relatively low relief (i.e. less than 300 ft) and gently dipping beds, chiefly because of the normally steep escarpment face of the asymmetrical ridges. These soils also become slippery when wet, and many relatively modest slopes would become difficult for wheeled vehicles because of loss of traction.

Dolomite hills or mountains

531. The landscapes formed in inclined dolomite which were examined for this report occur in the "folded Appalachian" district of northern

Alabama. Dolomitic rocks develop landscapes that strongly resemble those of limestones.

532. Regional drainage. Both the gross and low-order drainage patterns are commonly trellis type, usually with relatively restricted areas of dendritic or rectangular type. Unlike limestone hills, swallow-hole drainage does not occur.

533. Topography. The cross-sectional shape is rolling in humid regions, and crested in arid regions. Unlike limestones, dolomites do not develop sinks, and therefore basined landscapes rarely, if ever, occur. All other things being equal, dolomite tends to be slightly more resistant to erosion than limestone, and slopes tend to be slightly steeper and more rugged.

534. Local erosion. Similar to that of limestone hills.

535. Natural vegetation. Humid dolomitic regions were generally forested, with a probable density and size of tree slightly greater than those on limestone, although these distinctions are normally too subtle for airphoto identification. In arid regions vegetation may also be somewhat denser and taller than on limestone though the differences are normally slight.

536. Land use and construction practices. Similar to those on limestone hills, except that since dolomites are rarely used for either building stone or industrial purposes, quarries are considerably less prevalent in dolomite than in limestone.

537. Parent materials. Dolomites are commonly but not invariably massive. They are much less susceptible to solution than limestone, but strongly resemble it in color and strength.

538. Soil profile characteristics. Soil profiles are similar to those in limestone, but they tend to be siltier and slightly less plastic. All four dolomitic soils tested were classified as CL type.

539. Trafficability and cross-country movement characteristics. Although the soils of high and low topographic sites all classified as the same type (CL, soil trafficability class C), there appears to be a significant difference in characteristics as a function of topographic position. The lowland soils were more variable than upland soils.

540. From very limited data (two values each for high and low sites)

it appears that low sites are marginal for trafficability purposes; the RCI range was 72 to 128 during the wet season. Some areas will be marginal for vehicle categories 5, 6, and 7. The soils of the high sites tested were appreciably stronger; the RCI values were 148 and 149 during the wet season. Thus, it would appear that trafficability during the wet season is significantly better on ridges than in the valleys. Both sites are readily trafficable during the dry season.

541. Cross-country movement conditions are similar to those on inclined limestone landscapes of comparable relief.

Shale hills

542. Landscapes composed primarily of dipping shale strata are found in various places in the Appalachian system, in Arkansas, the southwestern states, and elsewhere in the United States. Shales are not usually resistant to erosion in any climatic regime. For that reason, shale ridges analogous to those formed by other sedimentary rocks are relatively rare. Almost everywhere the shale sequences which form ridges are found upon close examination to contain at least a few thin beds of more resistant rock, which help to "hold up" the adjacent shales.

543. Regional drainage. Both the gross and low-order drainage patterns are chiefly the trellis type, but in many cases the patterns are so distorted as to be difficult to recognize. For example, the drainage in fig. 48 is fundamentally trellis, but the only obvious quality is the overall angularity displayed by the pattern. Oddly, in humid regions drainage channels may be quite widely spaced, as illustrated in fig. 48. Low-order streams are often only swales without obvious scour channels, as illustrated by the one indicated by marginal arrows A in fig. 48. In arid and semiarid regions, channels tend to be quite close together, with obvious scour channels.

544. Topography. The cross-sectional shape in humid climates is generally rolling, as illustrated in fig. 48. All other things being equal, these surfaces are more subdued than those of any other rock type. In most shale hills, the topographic highs will display one, and more often two, strongly preferred orientations. In fig. 48, only one is in evidence; it is indicated by the double arrow below the photo. The ridge crests are almost invariably smooth and uniform. In arid climates the cross-sectional

shapes are commonly crested, but even in these climates these landscapes are more rounded than those developing in other sedimentary rocks.

545. Local erosion. Shale hills of low or moderate relief are not particularly susceptible of gully erosion. Note that no true gullies are in evidence in fig. 48. Where present, they are generally C type or very broadly V type with rounded upper edges. Gullies do, however, develop in areas of very steep slopes, and in such places are normally sharply V type. All other things being equal, gullies are predominant in areas of thick soil. In arid regions, however, the gullies form in the rocks, so that soil thickness is not a factor.

546. Natural vegetation. In humid regions these surfaces were commonly forested, even on steep slopes. However, on some steep slopes the normally closed canopy and tall forest give way to a relatively open stand of scrubby trees. These are the so-called "shale barrens" common in many areas of shale bedrock. In arid regions the shale slopes are somewhat more densely vegetated than analogous slopes on other sedimentary rocks.

547. Land use. Shale landscapes in humid areas are usually intensively cultivated, as illustrated in fig. 48. Where relief is moderate, such as the area illustrated in fig. 48, virtually the entire surface may be cultivated. There is a marked tendency for fields to be rectangular with the long dimensions parallel to the ridges. Very often the plow furrows are also oriented in this direction as an antierosion measure, so that there is often a faintly linear texture parallel to the ridges. Many of the fields in fig. 48 display this property. Crops are diversified, so that shales tend to display a wide variety of tones and textures in the field patterns (see fig. 48). Where relief is great, and side slopes of the topographic highs are very steep, the cultivation is normally confined to valley floors and ridge crests. In such instances, the field shapes tend to be somewhat irregular. Steep slopes are generally wooded. Contour plowing is extensive in some places, but may be completely absent in others, as shown in fig. 48.

548. Construction practices. In some areas fields are terraced, but as illustrated in fig. 48, such features may be completely absent in other places. Roads are generally somewhat sinuous, with alignments along the crests of topographic highs preferred. However, in areas of moderate

relief, the roads may be only very slightly influenced by topography. One reason is that, all other things being equal, shales are easier to excavate than other sedimentary rocks, and therefore ideal straight alignments can be approached more closely. Quarries are rare; where present, they are found in association with the kilns of ceramics plants.

549. Parent materials. The parent materials of this type of landscape are chiefly thick sequences of shale, but there are almost always thin beds of limestone or sandstone incorporated within them. Shales are widely variable in color. As a result, arid and semiarid regions commonly display a "banded" appearance because of alternating light- and dark-colored beds. In humid regions these color bands are generally so thoroughly masked by thick soils and vegetation that they cannot be detected. At best, they are usually visible as poorly defined variations in tone between topographic highs and lows.

550. Soil profile characteristics. In humid areas the soil profiles in valleys and on the gentler slopes are from 2 to 5 ft thick; on ridgetops they are generally much thinner. In general, the deeper soils consist of an A-horizon from 6 to 18 in. deep, composed primarily of ML soils, although other types (such as CL-ML or SM) do occur. The B-horizon is generally somewhat finer grained and more plastic than the A-horizon. The shallower soils are generally similar, but they tend to be interspersed with shale chips in varying degrees of decomposition. The soils of the "shale barrens" are very thin, and usually contain an abundance of chips. In arid and semiarid regions the soils are generally thin or absent, and usually consist of hardly more than a layer of slightly weathered shale chips.

551. Trafficability and cross-country movement characteristics. The soils in this landscape fell into soil trafficability classes C (CL) and D (SM, SM-SC, and ML). Only six soils were tested, but on the evidence of this very limited number of samples it appears that, in general, the SM and ML soils tend to occur on topographically high sites, while the SM-SC soil tends to occur in the lows. The CL soils occurred on both high and low sites.

552. The high-site CL soil (class C) was remarkably homogeneous in physical properties. It exhibited an RCI of 82 during the wet season. This soil is probably trafficable for tracked and all-wheel-drive vehicles

in categories 1 through 5 during the wet season, although with some difficulty.

553. The SM soil exhibited an RCI of 300+ during the wet season, and the ML soil had an RCI of 58. The SM soil would be trafficable to all vehicles, but the ML soil would be trafficable to category 1, 2, and 3 vehicles. Oddly, the most trafficable soil (the SM) and the least trafficable (the ML) both occurred on topographically high sites, while the intermediate soil (an SM-SC) occurred on a low site. No reason for this behavior is known. In any event, it is apparent that topographic position cannot be used as a criterion for route selection. The low-site SM-SC exhibited an RCI of 197 which would be trafficable to all vehicles.

554. Cross-country movement would probably be only slightly inhibited by steep slopes in shale hills while the soil is dry, but the relatively numerous gullies would be a handicap in areas of steep slopes. However, the soils are generally of types that become slippery when wet, and thus even the relatively subdued slopes might be difficult or even unclimbable after rains. The closely spaced trees on uncultivated slopes would probably be an additional inhibition.

Sandstone-shale hills or mountains

555. Landscapes in sequences of rocks composed chiefly of interbedded sandstone and shale display some unique features. In general, sandstone-shale sequences are relatively complex. In the eastern United States, these sequences commonly "begin" with a massive sandstone, followed by a considerable thickness of interbedded but relatively thin strata of shale and sandstone, followed by a thick sequence of relatively pure (i.e. incorporating only a few, very thin sandstone beds) shale, which may in turn be overlain by another massive sandstone member. It is essentially the landscape resulting from the erosion of a symmetrically folded sequence of this type in the eastern United States that is described herein.

556. Regional drainage. Both the gross and low-order drainage patterns are chiefly the trellis type, but there are generally more or less extensive areas of rectangular or dendritic type. In some places low-order dendritic patterns form in the floors of major valleys, as illustrated near the center of fig. 49.

557. Topography. The cross-sectional shape is almost invariably

crested, as illustrated in fig. 49. Those ridges formed of massive sandstone may have crests that are regular, smooth, or very slightly rounded; slopes, especially the escarpment slopes, tend to be straight and relatively featureless. A ridge of this type trends across the right center of fig. 49. The ridges composed of alternating beds of shale and sandstone commonly have very sharp crests. The crest is minutely serrate, and is composed of the upthrust edge of a resistant sandstone member. Broken fragments of this member frequently litter the escarpment slope beneath it. The dip slope of such ridges often displays an irregular banded appearance; under the stereoscope these usually resolve into subsidiary serrate ridges on the back of the main ridge, each light-colored band being the edge of an outcropping sandstone structure. All of these features are illustrated by the ridges crossing the upper left corner of fig. 49.

558. The valleys are normally carved in shale, and have the usual subdued topography. However, even here a thin sandstone may result in a persistent topographic high running through the valley parallel to the main ridges. An obvious example of such a feature is shown by arrows labeled A in fig. 49.

559. Local erosion. Gullies are rare on the ridges. Relief is usually too low in the valleys for gully formation, but where gullies do occur, they are chiefly C type or very broadly F type with rounded upper edges. Note the examples indicated by marginal arrows B in fig. 49. In some places erosion has removed the adjacent shale and left wall-like sections of resistant sandstone beds standing free. Note the excellent examples in the gorge in the upper third of fig. 49 where the railroad penetrates the ridge.

560. Natural vegetation. These surfaces were almost entirely forested, except in the occasional outcrops of bare rock. Where forests remain, they are commonly so open that the photo texture is flecked rather than botryoidal (see fig. 49). In some places the trees are so scattered that the vegetation is a savanna rather than a forest.

561. Land use. The valleys are cultivated where they are wide enough to provide a practical field. Field shapes are irregular, but not necessarily related by shape to the topography, as illustrated in fig. 49. The uplands are used for pasture, a practice that assists in maintaining

the open, savanna-like vegetation assemblages. Contour plowing and even terracing are practiced, as shown in fig. 49.

562. Construction practices. Road cuts in shale are generally relatively smooth-sided, and commonly cut back, especially when the cut is parallel to the strike of the beds, as along the railroad grade at the upper right in fig. 49. Cuts in sandstone are irregular and have vertical or near-vertical sides.

563. Parent materials. Parent materials are sandstone and shale in almost endless combinations of bedding thicknesses, textures, etc.

564. Soil profile characteristics. The soils of the massive sandstone ridges strongly resemble those of pure sandstone topographies. However, those soils developed on interbedded shale and sandstone ridges normally consist of components from both rock types, and are somewhat intermediate in type. Soils on low sites are commonly derived from shales, with varying amounts of adulteration from adjacent sandstones. The four samples examined in this study were all taken in northern Alabama. As would be expected in soils derived from such different parent materials, the soils are quite variable. The two samples from topographically low sites were classified as CL and ML, while those from the two high sites were SM-SC and SM. Thus, the low sites are dominantly silts and silty clays of low plasticity, while the high sites are coarser grained with even lower plasticity indices, suggesting that the sandstones tend to produce the uplands in this landscape.

565. Trafficability and cross-country movement characteristics. The soils of this landscape fell into soil trafficability classes C (CL) and D (SM-SC, SM, and ML). There is no apparent correlation between classes and topographic position, but there appears to be a tendency for coarse-grained soils to occur on high sites and fine-grained on low. The class C soil in a low topographic position exhibited an RCI of 61 during the wet season, suggesting that areas of this soil type would be trafficable only for category 1, 2, and 3 vehicles, and marginal for category 4 vehicles during the wet season.

566. The ML component of the class D soils in a low topographic position exhibited an RCI of 107 during the wet season in the same soil layer. This soil is apparently trafficable for all vehicle categories all

year round. The SM component of the class D soils in a high topographic position had an RCI of 146 and was trafficable for all vehicle categories. The SM-SC component of the class D soil in high topographic position, on the other hand, exhibited an RCI of 175 during the wet season. This is adequate to support all military vehicles.

567. In general, the data indicate that the lowlands are marginally trafficable during the wet season, while the uplands are easily trafficable, except in a few locations. The lowland soils, being finer grained, may also remain wet for considerable periods after a soaking rain, while the coarse-grained upland soils probably dry much more rapidly.

568. The sandstone ridges commonly are very steep, especially on the escarpment faces, with slopes up to 60% in some places. These slopes are almost invariably forested. They are probably unclimbable at any time, and especially during the wet season when the soils may become slippery. The terracettes and other subsidiary features produced by outcropping sandstone beds would also be a severe inhibition to movement across the "grain" of the country.

Limestone-shale hills or mountains

569. A relatively distinctive type of landscape forms in areas where a substantial amount of limestone is interbedded in a dominantly shale sequence. Such alterations of relatively thin limestone beds with thicker shale beds are very common in sedimentary rocks all over the world. The examples from which the following description was derived are chiefly from the folded Appalachians, and should therefore be applied only to similar sequences of rock in a humid climate at least roughly equivalent to that of the eastern United States.

570. Regional drainage. The gross drainage pattern is generally fundamentally trellis, but it is often asymmetric, and in many places is so distorted as to be difficult to recognize. The low-order patterns draining the topographic highs may also be trellis, but dendritic or rectangular forms are also common. Low-order patterns in the large topographic lows are commonly dendritic or crudely rectangular, as illustrated by the example indicated by marginal arrows A in fig. 50. Swallow-hole drainage may occur in some places, but examples are rare. Many low-order streams, especially in areas of rolling topography, display few apparent scour

channels; note those in the area marked by marginal arrows D in fig. 50.

571. Topography. The cross-sectional shape is normally a complex combination of rolling and crested, as illustrated in fig. 50. Marginal arrows B and C indicate crested areas, and marginal arrows D indicate an area of rolling shape. Only rarely do small areas of basined topography occur. Normally there are two preferred orientations of topographic features. The crossed arrows below the photo indicate the two orientations evident in fig. 50. Note that the small ridges tend to be aligned parallel to the long arrow, but that the trunk streams and facets on the steep face of the topographic high indicated by marginal arrows C are oriented parallel to the short arrow. Note also that the rolling topographic forms are more subdued than the crested forms. The topographic lows in many places consist of wide portions with undulating bottoms separated from each other by short stretches of rolling or crested topography through which the streams penetrate in V-shape valleys. This feature is well illustrated in fig. 50.

572. Local erosion. Gully formation is widely variable, depending on degree of slopes, thickness of soil, and type of material. Gullies are rare in areas of rolling topography, but usually fairly frequent in areas of crested shapes. In the latter places, they are usually V type, as illustrated by those indicated by marginal arrows E in fig. 50. Gullies draining very steep slopes often have very irregular longitudinal profiles, as illustrated by those draining the slope indicated by marginal arrows C. Rockfalls are often present at the bases of very steep slopes. Gullies, where present, in topographic lows are C type or very broadly V type, with flat gradients. Only rarely do they expose bare soil or rock.

573. Natural vegetation. These landscapes were almost totally covered by dense forest, with the largest trees commonly growing on the shale. The present second-growth forests normally do not adhere to this generalization.

574. Land use. The floors of the topographic lows are cultivated where they are wide enough to make cultivation practical. Only rarely are the ridges cultivated, and then normally only on the dip slopes. Note the examples of such "dip slope" fields in the upper left corner of fig. 50. Field boundaries are normally relatively irregular. Stone fences may occur

in some places. The existing forest cover is generally quite thin, and may photograph as a combination of botryoidal and flecked texture, as illustrated in fig. 50.

575. Construction practices. Terraces occur in many places, as illustrated near the bottom of fig. 50. Roads are sinuous and tend to follow topographic lows (see fig. 50). They tend to cross ridgelines in water and wind gaps. Quarries can be found in many places; they may be in either limestone or shale. When kilns for the manufacture of ceramics can be identified nearby, it is usually safe to assume that shale is being quarried.

576. Parent materials. The crested ridges are predominantly limestone, although they may contain interbedded shales. These shales may or may not be difficult to detect, depending upon local conditions. "Stepped" gullies imply the presence of shales interbedded in limestones. In the absence of "stepped" gullies, such interbedded sequences are rarely detectable as actual topographic irregularities; more commonly they can only be seen as faintly linear textures on the escarpment faces of the ridges. There is scarcely more than a suggestion of this feature on the escarpment in the upper left corner of fig. 50. Such bedding lineations are almost always parallel to the trend of the ridge. The parent materials of the ridges with rolling cross-sectional shapes, and of the topographic lows are predominantly shale. In some places distinct linear patterns of somewhat diffused light and dark tones trend parallel to the ridges; these may be the result of differing colors in the bedded shales, or they may indicate thin limestone beds intercalated in the shales. In the latter case, there is also commonly a slight tendency for a specific band to exhibit persistent, even though subdued, topographic expression. In general, the soils which develop on shales tend to photograph in darker tones than those which develop on limestones.

577. Soil profile characteristics. The soils on the crested topographic highs, which are chiefly derived from limestones, are generally thin and poorly developed. These soils are generally of the CL or CL-ML type, and may contain limestone chips in many places. Chert fragments are also found in some localities.

578. The soils on the rolling topography and in the topographic lows

are derived chiefly from shales with varying amounts of adulteration from the adjacent limestones. They are usually considerably thicker than the limestone soils, and may reach thicknesses of 6 or 7 ft in some places. Soils in swales in the topographic lows are generally somewhat organic, and tend to photograph in darker tones, as illustrated in many places in the valley floors in fig. 50.

579. Trafficability and cross-country movement characteristics. The five soils tested from this landscape type fell into soil trafficability classes C (CL) and D (CL-ML and SM). All samples were taken in northern Georgia. There appears to be little if any correlation between soil type or soil trafficability class and topographic position; the CL and CL-ML soils are represented by four samples, two from high and two from low sites. The single SM soil was from a high site.

580. The class C (CL) soils for both the high and low sites exhibited an RCI of about 195 (the range was 192 to 197 with 192 being the low site) during the wet season; these soils are probably trafficable without difficulty the year round. The CL-ML component of the class D soils exhibited RCI's from 111 for the low site to over 300 for the high site, and is also probably trafficable without difficulty the year round. The SM class D soil exhibited an RCI of 118 during the wet season. Although still trafficable for all military vehicles the year round, the SM soil would probably be hard to negotiate since it is found on the steep slopes of topographic highs.

581. Cross-country movement would be inhibited by steep slopes on the ridges, especially those with crested cross-sectional shapes, and in a few places by dense forest growth. The latter is generally sufficiently open to be passable, but would, in combination with the SM soils, probably be a considerable inhibition on slopes. Gullies would not be a serious obstacle in most places.

Landscapes in Igneous Rocks

Horizontally stratified rocks (basalt plains)

582. Stratified igneous rocks that cover a sufficiently large area to produce a characteristic landscape are chiefly lavas. In general, areas

of this type are those physiographic regions commonly called "lava plateaus" and "shield volcanoes." It is, of course, possible for such features as sills to produce landscapes of this type if the overlying non-igneous material is stripped away by erosion. However, this apparently happens rarely, and no examples of this type are included in this report.

583. Basalt plains are found in the Deccan of India, in Africa, Australia, Iceland, and elsewhere. The most extensive area in the United States is the Columbia Plateau region in Washington and Oregon. All lava surfaces are grouped in this discussion, despite the fact that surfaces of both high and low relief are relatively common. For example, fairly large areas of Washington and Oregon do not exhibit 500 ft of relief, and should therefore be classed properly as plains. (This type is illustrated in fig. 51.) However, this upland surface is cut at wide intervals by deep valleys and canyons, and in such places the relief may be several thousand feet.

584. Regional drainage. Drainage in basalt is often internal, acting much as in massive limestone. Obvious drainage channels are rare in many places. Where they do occur, the gross patterns are generally of the deranged type, or of a special variety of the swallow-hole type, in which the channels fade indeterminately into the surface. Lakes, ponds, and swamps of widely variable shapes and sizes may occur in humid areas. Low-order drainage is commonly either deranged or dendritic. Through-flowing streams are generally more or less entrenched, with tributaries occasionally joining them discordantly, so that cascades and waterfalls are common.

585. Topography. The general cross-sectional shape is blocky on a regional scale. Geometrically this configuration is a relatively plane surface cut by deep, precipitous gorges, in many places several hundreds or even thousands of feet deep. The upper surfaces of the blocky landscapes (i.e. the plain through which the canyons are cut) are chiefly rolling. In many places there are numerous basins of widely variable size and shape, as illustrated in fig. 51. The basins range in size from tiny depressions a few feet across to large ones covering almost a square mile, and in shape from smoothly circular or oval to exceedingly irregular. In some places they have been described as "ameboid." Local relief of these topographic high surfaces rarely exceeds 200 ft, and is commonly (as in fig. 51) much less. In many places the low-order stream valleys are tortuous.

586. In detail the surface is rough, being composed of innumerable small, irregular mounds in juxtaposition. These mounds are only a few feet to a few tens of feet across, and a few inches to several feet high. The resulting photo textures (often described as "scabby") as illustrated in fig. 51 are distinctive. Depending on the size, shape, and number of the mounds, the texture may be smoothly botryoidal (in which case the domes are usually dark and the intervening troughs light), flecked (normally light flecks on a dark background), or very finely mottled (usually the mottles are light against a dark background).

587. The sides of large stream valleys are very steep. They may be benched, and in some cases give the distinct impression of gigantic stairs. In some places the vertical or near-vertical sides of the benches are jointed into hexagonal prisms with the long axes vertical, the so-called "columnar jointing." In some places this is very distinct and constitutes a primary recognition feature; in others, it may be indistinct or absent. Rockfalls at the bases of the benches and on valley or canyon floors are common.

588. Local erosion. Lava surfaces rarely exhibit intense gully erosion. Where gullies do form, they are generally V type with moderately steep gradients. Rill and sheet erosion are rare.

589. Natural vegetation. Lava surfaces may have complex patterns of vegetation, as illustrated in fig. 51. The porous zones in this instance are marked by dense tree or shrub bands as a result of the abundant moisture contained therein. This is especially pronounced in arid or semiarid climates. In subhumid climates, such as that illustrated in fig. 51, the effect is slightly more subdued but still obvious. Commonly joint patterns or other fracture zones are sharply outlined by similar vegetation zones, chiefly because the fractures provide the root system with a passage to one of the porous strata. The basins so numerous in many lava areas frequently have porous zones outcropping near the bottom and are, therefore, commonly ringed with a vegetation band, as illustrated in fig. 51.

590. Land use. Land use depends closely upon climate. In humid regions lava surfaces may be cultivated, but in semiarid or arid regions they are used primarily for grazing. In subhumid regions the uplands are used for grazing, while flat valley bottoms and occasionally some of the

basin floors are used for agriculture. Crops are commonly grains or fodder, resulting in smooth photo textures. See the small cultivated basin in the upper right corner of fig. 51.

591. Construction practices. Roads on the topographic highs tend to be largely independent of topography, although they are aligned to avoid the larger and deeper basins. Canyon or valley crossings result in sinuous road alignments in many places. Lavas are used in many places for road material and other aggregates; quarries are usually vertically walled with irregular working faces.

592. Parent materials. Lava surfaces are produced by the erosion of successive flows of lava. Basalt is the most prevalent material, but both andesites and rhyolites are common in some localities. Although exceptions are numerous, the following generalizations usually apply.

- a. Gullies are least common in basalts, most frequent in rhyolites.
- b. Columnar jointing occurs mainly in basalts, least commonly in rhyolites.
- c. Basalts are darkest in color, rhyolites are lightest in color. The distinction is visible as variations in photo tones.

593. At the contact of each successive flow there is often a very permeable zone. This zone constitutes a plane of weakness in the rock, and is in general the agent responsible for the benches visible in valley walls. Such zones are also the channels by which incident water escapes from the surface. A primary recognition feature of basalt surfaces is the frequency of springs or water seeps from successive levels in the valley side.

594. Lavas are occasionally interbedded with ash and pumice, although these materials are rarely important.

595. Soil profile characteristics. Soil profile development is profoundly affected by climate. In arid and semiarid regions the soils are thin and poorly developed. In many places in such climatic regimes the soil is discontinuous, occurring only in topographically low sites, with bare knobs of rock exposed. In subhumid climates, soils are thicker and more or less completely mask the underlying rock. In such cases they vary from about 1 to 10 ft in thickness, depending chiefly on topographic position. The A-horizon is generally a moderately plastic sand or silty clay.

The B-horizon is commonly slightly richer in clay.

596. Trafficability and cross-country movement characteristics.

Only three sites were examined on lava surfaces, one each in Colorado, Washington, and Oregon. These soils fell into soil trafficability classes C (CL) and D (OL). Both class C soils were taken from topographically low sites (Colorado and Oregon); RCI's were 152 and 300+ during the wet season. On the basis of this very small sampling, it is probable that the soils of these areas are trafficable all year round for military vehicles.

597. On the other hand, the sample taken from Washington (from one topographically low site in the area illustrated in fig. 51) was classified as OL and exhibited an RCI of only 73 during the wet season. The soils of this area during the wet season would very likely be trafficable only for category 1, 2, 3, and 4 vehicles, and marginally trafficable for category 5 and 6 vehicles. This area has been glaciated, and it is possible that the soil tested is not representative of those formed on nonglaciated lava surfaces.

598. Lava surfaces are in general very irregular, both regionally and in detail. Cross-country movement would be inhibited in many places by more or less extreme surface roughness, and movement across the frequent deep, steep-sided valleys would be impossible in most places. Vegetation would not normally constitute an inhibition to movement.

Nonstratified igneous rocks
(granite hills and mountains)

599. In the sense used in this report, nonstratified rocks are those which do not exhibit topographic or other characteristics that normally develop in a landscape because of bedding. Thus, the igneous rocks included in this group are the so-called plutonic rocks which form in large masses (i.e. batholiths, laccoliths, etc.).

600. Granite and related rocks occur in every continent, chiefly in the so-called "shield" areas and in the central portion of mountain ranges. The sites examined for this study are in northern Georgia. The region is one of less than 500 ft of relief. The pertinence of the discussion which follows is confined to granitic areas of roughly this order of relief, and to regions having climatic regimes similar to that of Georgia.

601. Regional drainage. Both gross and low-order drainage patterns

are generally either dendritic or rectangular; both types often occur in juxtaposition. Where the rectangular pattern is evident, there are normally at least two well-developed joint systems at approximately right angles. The low-order drainageways often give the impression of enclosing individual topographic highs. This property is illustrated in fig. 52, but the effect is somewhat masked because the intensive cultivation and terracing have considerably altered the natural drainage.

602. Topography. The cross-sectional shapes in granite hills are generally rolling, as illustrated in fig. 52. The slopes from the topographic highs to the topographic lows are usually sigmoidal, although some streams flow in broadly V-shaped valleys. There is normally a distinct sense of randomness; the ridges between drainageways are short, often tortuous, and randomly oriented. They tend to break up into small, dome-shaped masses, as illustrated in fig. 52, rather than persist as continuous ridges with crests of relatively uniform elevation.

603. Local erosion. The soils of granite regions are peculiarly susceptible of gully erosion. Where no gully-control measures are taken, gullies are numerous. They are compound, with saucer-shaped segments near their heads and V type (or FV type) near their mouths.

604. Natural vegetation. This landscape was almost entirely covered with dense forest, the only exceptions being the bare rock domes such as Stone Mountain near Atlanta, Georgia.

605. Land use. Granitic areas in humid environments are commonly relatively intensively cultivated, as illustrated in fig. 52. Field patterns are irregular and markedly influenced by topography. The deeper and more precipitous valleys are wood lots, which tend to photograph in very dark gray tones, in contrast to the generally light tones of the fields. Crops are generally similar in any one region, so there is a distinct sense of homogeneity in any one photograph or small group of photographs.

606. Construction practices. The most striking pattern in this region is produced by the extensive terracing (or, in some places, contour plowing) of the fields to prevent gully formation and increase soil fertility. The overall impression is similar to that which would be achieved by drawing contour lines on a photograph. This pattern is illustrated in fig. 52. Granites are extensively quarried in some places; the quarries

are generally typified by smooth "stepped" working faces, with the risers of the steps vertical, and the treads nearly or perfectly flat.

607. Parent materials. The parent materials of this landscape may be any of the several forms of granite, plus some varieties of gneissic rock in which the degree of schistosity is low. When bare, these rocks commonly photograph in light gray tones, and are totally lacking in any trace of banding, such as results from the erosion of stratified rocks.

608. Soil profile characteristics. The residual soils of these landscapes are usually fairly thick, ranging in many places from 8 to 10 ft. In general the A-horizon is a silty and clayey sand (commonly SM) about 18 in. to as much as 40 in. thick, underlain by a more clayey soil as much as 6 ft thick in places. The soils of the landscape are relatively susceptible of sheet erosion, which results in an appreciable concentration of fines in topographically low sites. Thus, although both high and low sites tested classified as SM types, the soil on the high site is considerably coarser grained than that of the low. One result of this differentiation is that internal drainage in the low sites is considerably slower than in high sites, so that topographic lows tend to photograph in darker tones. This feature is illustrated in fig. 52. This difference in tone is commonly reinforced by the tendency of soils in low sites to be slightly more organic, and therefore darker in color, than those of high sites.

609. Trafficability and cross-country movement characteristics. Only two soils were tested for trafficability characteristics in this landscape, both in northern Georgia. Both the high and the low sites comprised SM (soil trafficability class D) type soil. However, the somewhat coarser-grained upland soil exhibited an RCI of greater than 300, while that of the lowland soil was only 155 in the wet season. Both of these soils are entirely trafficable for all categories of vehicles, except during extended rain periods.

610. Steep slopes rarely occur naturally in the landscape, except at the sides of gullies. Thus, in places where the surface configuration has not been artificially modified, steep slopes would not ordinarily constitute a problem, because the gullies can normally be readily avoided. However, when the landscape has been extensively terraced, as in fig. 52, the steep slopes and abrupt slope changes associated with the terrace edges

would be a serious inhibition to movement. In humid areas, the very dense tree growth in the deeper valleys would also be an inhibition to vehicular movement.

Landscapes in Metamorphic Rocks

Stratified (slate hills)

611. The bedding of many metamorphic rocks is so contorted or otherwise modified that it does not influence topographic development in any obvious way. The photo interpreter cannot detect such bedding, even though its presence may be suspected from background data. However, other features of metamorphic rocks, such as schistosity, may exercise profound topographic control, and thus give the illusion of bedding. For this reason, a special definition of bedding for metamorphic rocks seems advisable. In the sense used in this report, a stratified metamorphic rock is one which displays topographic or other features (such as color banding) which appear to be produced by bedding.

612. Slates and related rocks occur chiefly in areas which have been subjected to intense tectonic activity. The sites examined for this study are in Alabama. The area is one of considerably less than 500 ft of local relief. The pertinence of the discussion that follows is confined to slate areas of roughly this order of relief, and areas having climates at least roughly similar to that of the eastern United States.

613. Regional drainage. Both the gross and low-order drainage patterns are normally either dendritic or rectangular. It is not unusual to find two different patterns in juxtaposition. In areas where the parent material is strongly folded, or where one joint set is strongly predominant, the low-order pattern may be distinctly trellis type. Stream channels are relatively close together, but usually not quite so close as in shales.

614. Topography. The cross-sectional shapes are generally an association of rolling and crested areas, as illustrated in fig. 53. The floors of all except the smallest valleys tend to be flat-bottomed, such as that illustrated at the bottom of fig. 53. In such valleys, the break in slope between valley floor and valley side tends to be abrupt.

615. Local erosion. Gullies are relatively numerous, and almost

invariably the C type with gradients only slightly steeper than those common in shale landscapes. Where slopes are steep, gullies are sometimes F type, as illustrated by the one at the intersection of marginal arrows A in fig. 53.

616. Natural vegetation. Landscapes of this type were densely forested in the eastern United States.

617. Land use. Landscapes in slate are not quite as intensively cultivated as those formed on granites or gneisses, but there are many exceptions to this generalization. Fields tend to be somewhat irregular in shape, and to a marked degree controlled by topography. In general, the rolling portions of the landscape and the valley floors are cultivated, whereas steep slopes and the crested hilltops remain in forest. Contour plowing and terracing are very common in some places, as illustrated in fig. 53, but tend to be less thorough than on granitic and gneissic landscapes.

618. Construction practices. Roads tend to follow ridgelines on the rolling landscapes, but to avoid the crested hills and ridges. Quarries are rare. Many drainage lines are artificially straightened, as illustrated by marginal arrows B in fig. 53.

619. Parent materials. The parent materials of this landscape are chiefly thick sequences of slates or phyllites or both.

620. Soil profile characteristics. All other things being equal, the soil profiles on slates are considerably thinner than those on gneisses or granites. The A-horizon, which is rarely more than 6 in. thick, is generally either CL or ML. The B-horizon, which is commonly less than 4 ft thick, is somewhat variable, depending on topographic position and parent material. In general, the B-horizon is less plastic than the A-horizon. Low topographic positions tend to have B-horizons somewhat coarser grained than the A-horizon, with the reverse being common on high sites.

621. Internal soil drainage is generally slow. However, the upland soils drain more rapidly, chiefly because of topographic position rather than differences in soil character. This factor, coupled with the slightly higher organic content of the lowlands, tends to result in relatively light-toned hilltops and dark-toned lowlands, as illustrated in fig. 53. In general, soils developed on slates are relatively dark-colored, so that slate

regions tend to photograph in darker tones than most other metamorphic rocks.

622. Trafficability and cross-country movement characteristics. Of the two soils tested in this type of landscape, that from the high site was classified as CL (soil trafficability class C), and that from the low site as ML (soil trafficability class D). The trafficability characteristics of these two soils are almost completely anomalous. The class C soil from a high site exhibited an RCI of only 20 in the wet season, which makes it untrafficable for all military vehicles. No explanation for this behavior is known. The class D soil from a low site exhibited an RCI of 130 in the wet season which makes it trafficable for all vehicles.

623. Slopes would be an inhibition to movement on the crested ridges and hills and at the bases of the hills adjacent to large valleys in many places. The soils typical of this landscape tend to be slippery when wet, so that even relatively gentle slopes would be difficult to climb after rains. The dense tree growth common in some localities would be an inhibition to movement, especially when it occurs on the steeper slopes.

Nonstratified
(gneiss hills or mountains)

624. As used in this report, a nonstratified metamorphic rock is one which displays no topographic or other features as the result of bedding. In general, the rocks of this type are gneisses and schists.

625. Gneisses and related rocks occur on every continent, chiefly in shield areas and in regions which have been subject to intense tectonic activity. The sites examined for this study are in the piedmont areas of South Carolina. The region is one of considerably less than 500 ft of local relief. The pertinence of the discussion which follows is confined to gneissic areas of roughly this order of relief, and to regions having climatic regimes similar to that of the piedmont regions of the eastern United States.

626. Regional drainage. Both the gross and low-order drainage patterns are normally either dendritic or rectangular, and strongly resemble those exhibited by granite hills. In some places a somewhat elongate variation of either type may occur; this normally indicates the presence of two joint sets, one of which is more strongly developed than the other.

627. Topography. The cross-sectional shape is rolling. It strongly resembles granitic surfaces of comparable relief, but is slightly more ordered; that is, there may be a slight tendency for the generally short ridges to exhibit a preferred orientation. It must be emphasized that this tendency is lacking in many places. Slopes often exhibit a slightly more angular configuration than granitic landscapes, although the typically smooth sigmoidal curve is present in both.

628. Local erosion. Gneisses are very similar to granites in their susceptibility of erosion. Gullies are compound, with saucer-shaped segments near their heads and F type plus V type near their mouths, with a sharp break in gradient at the transition. Note the example at the intersection of the marginal arrows in fig. 54. The soils residual on gneisses are, like those on granite, susceptible of sheet erosion.

629. Natural vegetation. Gneiss areas in the eastern United States are generally heavily forested, especially on steep slopes.

630. Land use. Cultural practices are similar to those on granitic landscapes. Gneiss landscapes are normally intensively cultivated, with the irregularly shaped fields chiefly on the uplands, and the deeper valleys and steeper slopes are in forest. This feature is illustrated in fig. 54.

631. Construction practices. In many places the fields are extensively terraced or contour-plowed, as illustrated in fig. 54. The overall impression is similar to that which would be achieved by drawing contour lines on a photograph. Gneisses are less extensively quarried than granite; quarry faces may be either straight and "stepped" (dimension-stone quarried) or curved and irregular (road material, etc.). Roads are sinuous in most places, and tend to follow ridgelines, as illustrated in fig. 54.

632. Parent materials. Parent materials may be any one of the many varieties of gneiss. The rocks are commonly strongly jointed, usually with at least two sets at more or less right angles to each other. Depending on mineralogy and degree of schistosity, gneisses can be either very resistant to weathering and erosion, or very nonresistant. A wide variation in surface configuration is thus possible.

633. Soil profile characteristics. Soil profiles on gneiss are commonly thick, in some places reaching 12 to 15 ft. The A-horizon is

commonly silty or sandy, and in many places is only 6 to 9 in. thick. The B-horizon is usually more clayey, and considerably more plastic. The topographically high sites are frequently, but by no means invariably, coarser grained than the low sites, but this distinction is generally confined to the A-horizon. For example, in the two sites tested in this landscape, the high site had an SM-SC soil in the 0- to 6-in. layer, and the low site an ML soil, whereas in the 6- to 12-in. layers the soils were somewhat more plastic.

634. Trafficability and cross-country movement characteristics. The soil from a low topographic site (CL, soil trafficability class C) exhibited an RCI of 83 during the wet season, while the soil from the high site (CH, soil trafficability class B) exhibited an RCI of 300+. This very large difference in trafficability properties is probably at least in part a reflection of the difference in soil moisture.

635. The high sites would apparently be trafficable for all military vehicles all year round. On the other hand, the low sites would probably be untrafficable for category 6 and 7 vehicles during the wet season, or after soaking rains during the dry season. Steep slopes rarely occur naturally in this landscape type, except as the sides of gullies. Thus, in places where the surface configuration has not been artificially modified, steep slopes would not ordinarily constitute a problem, because the gullies can usually be easily avoided. However, where the landscape has been extensively terraced, as in fig. 54, the steep slopes and abrupt slope changes associated with the terrace edges would be a serious inhibition to movement. The very dense forest in the deeper valleys would also be an inhibition to vehicular movement.

Nonstratified (schist hills or mountains)

636. Schists and related rocks occur chiefly in areas which have been subjected to intense tectonic activity. The sites examined for this study are in the piedmont region of northern Georgia. The area is one of less than 500 ft of local relief. The pertinence of the following discussion is confined to schist areas of roughly this order of relief, and having climatic regimes at least roughly similar to those of the eastern United States.

637. Regional drainage. Both the gross and the low-order drainage patterns are usually either dendritic or rectangular, but not uncommonly there is a distinct tendency toward the trellis type. Any combination of the three types may occur in juxtaposition. There is usually a distinct sense of angularity about the low-order drainage patterns, as illustrated in fig. 55. The dendritic or rectangular patterns are elongated in some places; the direction of elongation usually coincides with the dominant strike of the schistosity.

638. Topography. The cross-sectional shapes are either rolling or crested, the former chiefly confined to areas of low relief and the latter to regions of high relief. Fig. 55 illustrates an intermediate form, in which the ridgetops and valley bottoms are slightly rounded, but in which the side slopes tend to be relatively straight for considerable distances. For equivalent amounts of local relief, schist regions tend to have a somewhat more angular appearance than other metamorphic rocks.

639. Local erosion. Residual soils on schists are commonly susceptible of gullying. Gullies are normally V type, as in the areas pointed out by the marginal arrows in fig. 55. Sheet erosion is common on unprotected slopes.

640. Natural vegetation. Schist regions are chiefly covered with forest of variable types and densities, depending to some extent on the nature of the parent materials. Highly quartzitic schists appear on somewhat fragmental evidence to have been covered with somewhat more open forests than those covering other types.

641. Land use. Schist areas are relatively intensively cultivated, but there are many local variations. Field outlines are generally irregular, and tend to be strongly influenced by topography. Contour plowing and terracing are extensively practiced. Wooded areas are generally confined to the steeper slopes. Crops in any given district tend to be relatively uniform, with the result that most fields display similar photo tones and textures.

642. Construction practices. Secondary roads tend to roughly follow ridgelines. Clusters of farm buildings are commonly, but not invariably, situated on ridgetops or hilltops. Quarries are rare.

643. Parent materials. Schists are exceedingly variable both

mineralogically and in degree of resistance to erosion. Chlorite, hornblende, and talc schists commonly weather readily, and therefore tend to produce somewhat more subdued landscapes than the more resistant types, such as calcareous and quartz-muscovite schists. However, there are many exceptions to this generalization.

644. Soil profile characteristics. The thickness of the soil profile is to a considerable degree dependent upon the type of schist; chlorite, hornblende, and talc schists weather rapidly, and produce residual soils 10 to 12 ft thick in places, while quartz-rich schists may weather only very slowly, and the residual soils may be less than half that thick in places. The two soils tested in this landscape classified as CL in the 6- to 12-in. layer in the topographically low site, and SM in the high site for the same soil layer. The high site consisted of a soil appreciably coarser grained than that of the low site, suggesting that sheetwash is an effective agent in soil formation in this landscape.

645. Most soils derived from metamorphic rocks are relatively light in color, and tend to photograph in light tones, as illustrated in fig. 55. However, the chlorite and hornblende schists produce dark-colored residual soils in some places.

646. Trafficability and cross-country movement characteristics. The soil of the topographically low site fell into soil trafficability class C (CL), and that of the high site into class D (SM). Oddly, despite being coarser grained and on a high site, the class D soil exhibited the worst trafficability properties. The class D soil displayed an RCI of 134, while the class C soil displayed an RCI in excess of 300. Both of these soils are probably trafficable all year round for all military vehicles.

647. Steep slopes would be an obstacle in a few places, as for example in crossing the valley in the upper left corner of fig. 55. The short but normally steep slopes of artificial terrace edges would also be a serious cross-country movement obstacle in many places. The dense tree growth in the deeper--and steeper--valleys would also constitute an important inhibition to movement.

PART VII: PROCEDURES FOR AIRPHOTO ANALYSIS OF TRAFFICABILITY

Introduction

648. The procedure for examining and interpreting airphotos normally follows a relatively standard pattern, regardless of the purpose for which the interpretation is being made. Nevertheless, interpretations aimed at the establishment of trafficability conditions do require special care, chiefly because the end result, namely an estimation of soil strength and obstacle density, is invariably achieved by an elaborate process of inference. In this sense, photo interpreters are faced with an almost unique problem. For example, a forester can normally see, and in many cases actually measure, the things in which he is interested, such as height and crown coverage of the trees. In contrast, the trafficability interpreter can rarely see, and can never directly measure, the precise factors in which he is interested, such as soil texture and moisture content. As a result, the interpretive process for trafficability purposes is commonly more elaborate than for other purposes.

649. Still another peculiarity of photo interpretation for trafficability purposes is the fact that seasonal and even short-term weather changes profoundly affect trafficability characteristics in many places. For this reason, it is necessary to have photos taken at different seasons or at least during different periods of short-term weather cycles. This is useful even when knowledge of seasonal variations is not required, because some soil properties can be deduced only from the manner in which they respond to changing conditions. For example, it might be impossible to differentiate between a silty and a sandy soil if the photographs were taken after an extended dry period when soil moisture levels were low, whereas the same soils might be easily differentiated if the photos were taken soon after a rainy period. In this instance, the silty soils would presumably drain more slowly than the sandy soils, and because of a greater moisture content would photograph darker.

650. With these limitations and requirements in mind, it is possible to establish a general procedure for the analytic process employed in airphoto interpretation for trafficability purposes. This procedure

is diagrammed in table 11, and discussed in the following paragraphs.

Analytic Procedure

Step 1: Select study area and define purpose

651. The scale of photography used and the area or areas to be covered are to some extent functions of the purpose of the study. For example, if trafficability estimates are to be made for an entire geographic region, the interpreter will be forced to select a series of representative areas for detailed study. These areas may then be photographed at large or medium scales (i.e. approximately 1:10,000 to 1:20,000), and the trafficability determinations made therefrom extended to other unphotographed areas on the assumption that they are analogous. On the other hand, if the objective is coverage of a specific route of approach, then the entire route might be photographed, and a detailed analysis made of it.

Step 2: Assemble photomosaic

652. With the area selected and the purpose defined, the next step is to assemble a photomosaic of the entire region of interest. The mosaic may be made by any of several photogrammetric techniques (this is advisable if planimetric accuracy is required), or it may be an uncontrolled type, made by matching complementary images in the overlap and sidelap areas of alternate prints and adjacent flight lines, respectively. Unless duplicate sets are available, it is necessary that alternate prints be used; the unassembled photographs are then available for stereoscopic study.

Step 3: Tabulate general background data

653. Prior to undertaking a photo interpretation study, the analyst should familiarize himself as thoroughly as possible with the known properties of the region. This familiarization should especially include the following information if available:

- a. Geologic information, including rock types, structural data, and erosional or depositional history.
- b. Climate and weather information.

- c. Vegetation types.
- d. Soil types, including the World Soil Group, plus other information in as much detail as possible. (The USDA county soil surveys are excellent references for this type of information.)
- e. Population type and density.
- f. Land use, including varieties of crops, rotation practices, or any other peculiarity of human occupancy.

The importance of background information cannot be overestimated. An analyst can recognize and properly interpret only those things with which he is already familiar either through direct experience or through communication to him of the experience of others.

Step 4: Inspect for photo quality

654. The degree of reliability of any photo interpretation is profoundly affected by the quality of the photographs employed. Much photogrammetric precision is lost if the photos are even slightly out of focus. Differences in tone as a result of variations in development or printing may make interpretation difficult. The adequacy of the scale of the photographs should be evaluated. Scales which are too small (or, in rare instances, too large) for the purpose of the study at hand will inevitably result in unreliable interpretations. Focal length of the camera used should be evaluated, because this to a considerable degree controls the amount of relief that can be detected. Cameras with 6-in. focal length are preferred. The time of day, as well as the season, should be determined. A summer photograph is of only limited usefulness in estimating spring trafficability characteristics. Thus, accurate results are to an important degree a function of photo quality; it is useless to expect precision when the basic data are inadequate.

Step 5: Inspect the photo-mosaic for regional patterns

655. Examination of the mosaic generally provides information on only the gross features of a region. These are commonly:

- a. Regional drainage type. Every effort should be made to classify the regional drainage types according to the system outlined in fig. 9, fig. 10, and table 4. Each area that is distinctive as to drainage pattern should be delineated.

- b. Land use and vegetation patterns. Among the most striking regional patterns are those produced by variations in land-use practices, especially if the region is densely populated, or by variations in the natural vegetation if the region is thinly populated. Each distinctly different type should be delineated; it will frequently be found that the drainage regions and land-use patterns coincide.
- c. Cultural activity. Areas of urban development, highway and railroad systems, manufacturing districts, quarrying or strip-mining areas, and other large-scale evidences of cultural activity should be identified and recorded.

Step 6: Classify homogeneous patterns into preliminary regions

656. With the data available from step 5, the study area can be divided into regions that are visually homogeneous at the scale of the photo-mosaic. Each such region will then have, throughout its area, the same type of regional drainage, the same land use, the same vegetation pattern, and the same types and degrees of cultural activities.

Step 7: Select areas to be studied in detail

657. This step is required only in those instances where the study covers so large an area that it is impractical to study it in detail in its entirety. In such instances, the regions delineated by the procedure outlined in step 6 provide a basis for the selection of typical areas. At least one area in each region should be selected for detailed study. The results of this study can, with some confidence, be extrapolated to other areas within the same regional type. It is often of great benefit to select at least a few of these special areas in such way that they are crossed by regional boundaries; the transition zones between regions are often very important in deducing the nature of the "core" areas.

Step 8: Inspect the selected areas stereoscopically to refine regional boundaries

658. This preliminary examination should be directed toward identifying and classifying the following properties:

- a. Regional drainage, according to the system outlined in table 4. Unlike the procedure of step 5, which was aimed at general patterns, this examination should classify each drainage pattern, or even each part of a single drainage

pattern in those instances in which they are perceptibly different. In addition, the channel types should be classified.

- b. Surface configuration, according to the system outlined in paragraphs 84 through 88, Part III. In most instances this will involve a photogrammetric determination of slopes.
- c. All gullies should be classified as to type according to table 5, and all anomalous types should be noted and recorded.
- d. Each vegetation type that results in a clearly distinctive appearance on the photos should be recognized and noted.
- e. All variations in cultural activity, such as variations in agricultural practices, variations in road patterns or types of construction, etc., should be noted.

659. In most instances, when the photographs are examined in detail, it will be noted that the preliminary regional boundaries do not represent valid divisions. Accordingly, the preliminary boundaries must be refined to make them representative of actual conditions.

Step 9: Erect new regions if needed, or combine regions if appropriate

660. In some instances, detailed study will reveal that an area which looked homogeneous at the scale of the photomosaic will be found to be composed of two or more distinctly different regions at the scale of the stereoscopic photographs. These new regions should be carefully studied, and the regional boundaries adjusted to mark them.

661. It is also possible that an area divided into two regions on the basis of the photomosaic may be discovered to be identical when viewed at a larger scale. For example, a plowed area may look quite different than an unplowed area, despite identical terrain configuration and soil types. It should be recalled that a photograph records only an infinitesimal instant of time; a day after the photographs were taken, the whole area might be plowed.

Step 10: Tabulate the physical characteristics of each region

662. Data are now available to permit detailed tabulation of the physical characteristics of each region. Such tabulations should include all available information, including drainage pattern type, channel type,

surface configuration, relief, vegetation, land use, cultural development, and other factors that have been noted.

Step 11: Classify the
landscape of each region

663. The tabulation achieved in step 10 theoretically provides the information necessary to classify each region as a specific landscape type, such as those described in Parts V and VI. Unfortunately, it is sometimes found that the facts may fit two or more possible classifications. For example, it may be extremely difficult to differentiate between a sandstone and a shale plain at this stage. However, the most likely classifications should be accepted as a preliminary step. This process results in an identification of the parent material type.

Step 12: Identify parent materials and soil types

664. From this, by comparison with Parts V and VI and Appendix B, the probable soil types present in each region can be deduced. Caution should be exercised at this juncture, because soils under certain conditions or positional relations may not be typical of the region in which they are found. For example, assume an area of sandstone overlain by shale, and eroded to the point where shale exists only as caps on the topographic highs. The general configuration of the landscape may be clearly derived from sandstone, yet the soils of both slopes and alluvial valley floors will not be typical derivations of sandstone alone. A systematic device for the detection of such anomalies is needed.

Step 13: Tabulate probable minor characteristics
of soil and landscape types

665. The first step in this procedure is to tabulate the expectable attributes of the soils found in each region. For example, in the case cited in step 12, the tabulation might include (see "Sandstone plains," paragraphs 430 to 433) the following:

- a. Valley cross sections U-shaped; bases of slopes indistinct. Very steep or vertical cut banks may be present in some places.
- b. Gullies probably rare or absent; if present, they will be V type with steep gradients. Rill scars may be present.

- c. Photo tones should be very light, especially those of areas of bare soil. Good internal drainage will probably produce lighter photo tones on crests of topographic highs than on side slopes or topographic lows.

**Step 14: Examine in detail for
presence of minor characteristics**

666. With the tabulation for a guide, a rigorous stereoscopic examination of each region should be made. If any one, or several, of the expectable characteristics is found to be missing, the region should be examined in still greater detail, and a new tabulation of its minor features worked out. If all expectable features are present, the landscape type, parent materials classification, and soils determination can be accepted without further examination.

**Step 15: Refine boundaries or
regional definitions, if necessary**

667. In those instances where the minor features found are not those expected, the new tabulation must be used. The actual features are matched against those that would characterize possible alternative parent material and soil types. This process of tabulation and reexamination should be conducted as many times as is required to make hypothesis and facts match. It will often be found that peculiar and unexpected combinations of factors will conspire to produce anomalous soil types. In such cases, it may be necessary to either refine the regional boundaries previously established, or even erect new regions on the basis of new data.

**Step 16: Estimate soil
trafficability for each region**

668. With the soil types established for each region with all possible accuracy, the RCI of each can be estimated. Care must be exercised that moisture conditions are taken into account. Since moisture condition is in many cases closely dependent upon the topographic position and the depth of the water table, if any, these factors must be carefully considered. In this context, it should be kept in mind that moisture regime may strongly influence the soil-forming processes. For example, a topographic position such that the soil remains perennially wet may result in the accumulation of such amounts of fines and organic materials as to affect the RCI, even though the parent

materials suggest soils of quite different properties.

669. With these determinations, areas of similar RCI can be identified and delineated. The seasonal variations in RCI of such areas can also be described; whether such areas can be recorded on the final terrain trafficability map is, of course, dependent upon the scale of that map.

Step 17: Examine stereoscopically for evidence of obstacle factors

670. Soil trafficability data alone are by no means enough to permit an estimate of the ease of vehicular movement through an area. Accordingly, the next step is to reexamine the photographs for evidence of the presence of the obstacle factors described in Part II. A standard method of providing a measure of the occurrence of such features as ditches, banks, terraces, and ravines or gullies is to lay out on the photographs a series of randomly placed straight lines, measure and tabulate the distance between such obstacles along the lines, and compute the mean of those distances. Thus, a value of 0.38 mile means that a vehicle traveling in a straight line through a region will encounter a ditch, bank, or gully on the average of once every 0.38 mile. The above-mentioned features can usually be seen directly or readily inferred. Others, however, such as boulders, rill scars, hummocks, etc., may be too small to be seen at the scale of the photographs. In such cases, every effort should be made to deduce their presence, because many slopes which would otherwise be negotiable are actually impassable because of such features.

671. The effect of vegetation on vehicular movement must be estimated. In general, the most satisfactory method appears to be an estimation of the amount of detouring (i.e. path length extension) required to thread a way through the trees. Such estimates can generally be made from an evaluation of the crown size and spacing of the trees. However, the effects of small trees, shrubs, reeds, or even tall grains such as corn, on visibility, and therefore on the relative difficulty of path selection, should not be neglected. In some instances the presence of vegetation may be of benefit to vehicular movement. For example, a sod cover over sand may stabilize the surface and make the soil trafficability appreciably better.

672. The effect of streams and lakes should be carefully evaluated.

If possible, bed and bank conditions should be deduced, and water depth and current velocity should be estimated.

673. Such cultural features as would either impede or assist movement should also be evaluated.

Step 18: Tabulate obstacle factors in each region

674. With the data from step 17, a tabulation should be made of all significant obstacles to movement that are present in each region. From this tabulation it is usually possible to develop a meaningful, although not necessarily quantitative, scale of values for each region.

Step 19: Subdivide regions on basis of obstacle factors, if necessary

675. The tabulations of obstacle factors will not uncommonly demonstrate that some or all of the regions contain two or more subregions having quite different spectra of obstacles. These subregions should be delineated in such fashion that each area is homogeneous in terms of vehicular movement.

Step 20: Tabulate terrain trafficability characteristics of each region

676. It is now possible to tabulate the entire spectrum of terrain trafficability characteristics of each region. In general, this tabulation should include at least the following:

- a. Trafficability soils group (table 3), or the RCI for the period of the year on which interest is centered (table 3 and Parts V and VI).
- b. Characteristic and extreme slopes (fig. 11).
- c. Surface characteristics, including microrelief, vegetation, and cultural features.
- d. Hydrographic characteristics.
- e. Special conditions, not accounted for elsewhere. For example, the properties of dry clean sand are not entirely accounted for by the soil trafficability group and the CI; in such instances additional description is necessary.

Step 21: Construct final terrain trafficability map

677. Because all the real work has already been accomplished, this step normally involves no more than providing the regions with appropriate

descriptive names and formalizing a legend. However, in those instances where separate study areas are used, it is necessary to extrapolate the boundaries on the study areas into unstudied districts. This is normally easy, because by this time the interpreter has achieved a "feel" for the landscape in question that permits extrapolation with considerable confidence.

PART VIII: EXAMPLE OF PHOTO INTERPRETATION

678. The example of photo interpretation for the purpose of estimating the cross-country movement characteristics which follows has been selected to illustrate the analytic procedures developed in Part VII. It has been chosen to illustrate widely variable conditions of topography and parent materials. The analytic process is described in exhaustive detail, so that the reader can familiarize himself with both the mechanics of the procedure and the logical processes involved.

Step 1

679. The study area is the portion of Hart County, Kentucky, covered by USDA photographs ALO-2V-26 through -34, and ALO-2V-56 through -64. This area is outlined in fig. 56.

680. The purpose of this interpretation is to estimate the strength (RCI or CI) of the soils in this region, and to establish the nature and magnitude of obstacles to cross-country movement of standard military vehicles.

Step 2

681. Fig. 57 is an uncontrolled photomosaic of the study area and the immediately adjacent territory. The scale of the mosaic is approximately 1:95,000.

Step 3

682. From background information, the following data are available:

- a. From a geological study of the Princeton, Kentucky, area³⁰ and a geological map of the area,³¹ it can be determined that the region is composed predominantly of limestone. However, overlying the thick limestone, and capping at least some of the higher hills, is a massive sandstone. Interbedded sandstones and limestones occur in some places. There is extensive faulting across the northern end of the study area, suggesting that lithologic relations will be complex.

- b. The climatic type for this region is D-2 (see Appendix A).
- c. The original vegetation was chiefly a tall forest of mixed hardwoods, with some conifers.
- d. No background data on soils of the area were available for the study.
- e. The population is chiefly rural, living on scattered farms. There are several small towns or hamlets.
- f. Much of the land is intensively cultivated, with a large portion of the acreage in crops suitable for grazing. No other data were available for the study area.

Step 4

683. The component photos indicate no striking variations in exposure or development processing; therefore, interpretation on the basis of variations in photo tone will be approximately constant throughout the study area. Even though the mosaic is uncontrolled, the surface patterns align readily at the photo margins, suggesting that tilt and attitude variations have been held to a practical minimum. Therefore, geometric values of direction, distance, and vertical dimension will be relatively constant throughout the study area. The scale of the component photographs is 1:20,000, and the focal length of the camera is 6 in.; relief will therefore be sharply exaggerated and relatively easy to interpret in the stereo-image. The date of photography is August 1958. Autumn photography shows a minimum of contrast in photo tones resulting from variations in soil moisture; therefore, very small changes in tone will have to be sought and interpreted.

Step 5

684. Regional drainage consists of a through-flowing stream, with a single channel of meandering type. Otherwise, there are no obvious drainage lines. However, the upper one-fourth of the mosaic (fig. 57) exhibits a pattern of land use which suggests that drainage of a dendritic or pinnate type may be present.

685. The land-use patterns are of four fundamental types: (a) areas dominated by rectangular or polygonal fields; (b) areas dominated by an

association of irregularly shaped fields and woodland; (c) areas dominated by linear or elongate fields associated with woodland; and (d) areas of elongate fields aligned parallel to the through-flowing stream. These variations in pattern suggest at least four fundamental variations in environment.

686. The roads are almost without exception sinuous, and exhibit a marked tendency to avoid the wooded areas, suggesting that the wooded regions represent either directly or indirectly some form of topographic barrier. The towns are small, and do not lie directly on the through-flowing stream; the latter fact suggests that some form of topographic barrier exists which makes it impractical to build close to the stream. Further, the towns are not located in, or close to, the major wooded areas, again suggesting that the wooded regions are topographically or otherwise unsuited for settlement.

Step 6

687. In summary, four regions can be tentatively recognized from the mosaic. Each is essentially homogeneous with respect to regional drainage, land use, vegetation pattern, and cultural activity. These regions are:

- a. Region 1. Regional drainage (table 4) is nonintegrated; land use consists of rectangular or polygonal fields; the region is almost completely under cultivation; roads are sinuous and avoid the few wooded areas or enclaves.
- b. Region 2. Regional drainage is nonintegrated; land use consists of an association of irregularly shaped fields and wooded areas; the region is chiefly wooded; the roads are very sinuous, especially where penetrating the wooded areas.
- c. Region 3. Regional drainage is apparently integrated or partly so, and of basically dendritic type, with a tendency for the low-order pattern to be pinnate; the land use consists of elongate fields arranged in crudely pinnate or dendritic pattern, separated from each other by woodland; the region is chiefly woodland; the roads are sinuous, with a tendency to avoid wooded areas.
- d. Region 4. The regional drainage consists of a single through-flowing stream characterized by a single meandering channel; the land use consists chiefly of elongate fields approximately parallel to the stream channel, with wooded strips bordering both sides of the fields; roads tend to

cross this region at approximately right angles, or to avoid it entirely.

688. The study area, as defined in step 1, is accordingly subdivided into the four regions defined above. These regions are delineated in fig. 56.

Step 7

689. On the basis of the regions delineated in step 6, the areas outlined by the dashed lines in fig. 56 are selected for detailed study. These areas were selected because they provide places where regional boundaries could be studied with a view toward modification or refinement, if detailed study warrants.

Steps 8 and 9

Area A

690. In Area A (see fig. 56 for location, fig. 59 for stereopair, and fig. 58 for regional boundaries and notations), even a cursory inspection with the stereoscope reveals that the boundary between Regions 2 and 3 (indicated by the dotted line in fig. 58) is not significant in its present position. Closer examination reveals that the distinction between areas of integrated drainage (Region 3) and nonintegrated drainage (Region 2) loses some of its significance at the scale of fig. 58 (1:20,000). For example, the valley which passes across the center of the photograph from northwest to southeast changes character at about the point marked A in fig. 58. Above this point, the valley has clearly defined scour channels and no basins, while below this point the scour channels rapidly fade out and a number of basins appear. The area of cultivation on the lower one-fourth of fig. 59, which superficially resembles a somewhat pinnate drainage pattern, is actually a series of semiconnected basins. The area at the upper left corner of fig. 59 is also composed of a basined surface.

691. Examination of the wooded versus the cultivated area in fig. 59 reveals that land use appears to be based primarily on the degree of slope. In general, the steep slopes tend to remain woodland, while the gentler

slopes are cultivated, although there are many exceptions to this generalization. In addition, the taller topographic highs, as at point B in fig. 58, are ringed by a poorly developed escarpment near the top, suggesting a fundamental change in parent materials. No basins have developed in the areas enclosed by the escarpments, but basins are numerous on the lower slopes of the topographic highs.

692. On the basis of the data from paragraphs 690 and 691, Area A can be subdivided into two regions, 2' and 3', as illustrated by the dashed lines in fig. 58. The parent material of Region 2' is almost certainly massive limestone, while that of Region 3' is probably sandstone, possibly with thin interbedded limestones.

Area B

693. Detailed examination of Area B (see fig. 56 for location, fig. 61 for stereopair, and fig. 60 for notations and regional boundaries) reveals the same general relations as for Area A (see dashed lines in fig. 60). In addition, there is an area of cultivation in the upper middle section of fig. 61 in which the generally smooth textures and even tones of the fields are interrupted by light-toned mottles and flecks, suggesting that a different parent material is involved, despite the fact that it occurs on a basined surface not obviously different geometrically from the basined surfaces elsewhere, such as that in the lower left corner of fig. 61. This area has been marked off as Region 5' in fig. 60, and reserved for more detailed study at a later stage. The boundary of Region 1 can also be refined, chiefly on the basis of the degree of slope. This is delineated in fig. 60, and the resulting area labeled Region 1'.

694. The smooth textures and uniform tones of Region 1' are strongly similar to the characteristics of the area in the upper left corner of fig. 61, which has previously been classified as part of Region 2'. This area, although apparently of less local relief than Region 1' elsewhere, and with basins somewhat less well developed, is nevertheless tentatively classified as Region 1'.

Area C

695. Detailed examination of Area C (see fig. 56 for location, fig. 63 for stereopair, and fig. 62 for notations and regional boundaries) reveals a series of areas mottled and flecked in a manner similar to those

noted in fig. 61; these are delineated in fig. 62 and classed as Region 5'. The major part of the area is similar to that previously defined as Region 2'. In addition, the through-flowing stream has a discontinuous topographic low associated with it. This has been defined as Region 4' in fig. 62. The edges of this region can be more carefully delineated, as indicated in fig. 62, chiefly on the basis of the almost completely flat surface. This region is renamed Region 4'. The very steep walls bounding this topographic low in many places do not appear to differ in any important respect from the areas classified as Region 2'; they are accordingly classified as Region 2'.

Areas D, E, and F

696. Since detailed examination of Areas D, E, and F (see fig. 56 for locations) revealed no new relations, these areas are not illustrated. Each region is now visually homogeneous at the scale of the stereopairs, namely 1:20,000.

Step 10

697. The general characteristics of each region are as follows (see tables 4 through 10):

- a. Region 1'. The gross drainage pattern is the nonintegrated swallow-hole type. Surface configuration is rolling and basined, with no tendency toward a preferred orientation. The local relief rarely exceeds 100 ft, and is in most places much less. Predominant slopes are less than 20%, but small and isolated areas may slope as much as 50%. The gullies are C type, with low gradients. Natural vegetation was probably relatively open forest. The region is predominantly under cultivation. Road alignments are sinuous and tend to remain on topographic highs.
- b. Region 2'. The gross drainage pattern is nonintegrated swallow-hole, but with generally better developed and longer channels leading to them than those in Region 1'. The low-order drainage tends to be crudely dendritic. Surface configuration is rolling or crested, and basins are more elongate or otherwise irregular than in Region 1'. The local relief rarely exceeds 20 ft, and in most places is much less. The predominant slopes are less than 50%, but small and isolated areas may slope 100%, and a few of them may have sides that are nearly vertical. The gully types are difficult to assess because most of them are

masked by trees, but there is some evidence that those forming on slopes below topographic highs capped with areas of Region 3' are V type with relatively steep gradients. The original vegetation was probably relatively open forest. The region is at present an association of cultivated fields, which are confined chiefly to areas of moderate slope (i.e. less than 30%), and open woodland, which is most commonly confined to the steeper slopes (i.e. those in excess of 30%). Roads are generally sinuous, and tend to follow side slopes just above the floors of topographic lows. Some quarrying is in evidence; the working faces tend to be irregular but vertical (see fig. 58 at point F).

- c. Region 3'. The gross drainage pattern is integrated dendritic with a marked tendency for the low-order drainage to be pinnate. The surface configuration is crested or blocky, and valleyed. Local relief rarely exceeds 200 ft, and in most places is much less. The predominant slopes are less than 40%, but small and isolated areas may have slopes of up to 60%, and some topographic highs may be partially ringed by a near-vertical escarpment. The gullies are V type with steep gradients. The original vegetation was probably dense forest. The region is at present an association of cultivated fields, which are confined chiefly to the more gentle slopes (i.e. those generally less than 30%), and woodland, which is confined to the steeper slopes (i.e. those generally more than 30%). Roads are sinuous, and are located chiefly near the floors of topographic lows. No quarrying is evident.
- d. Region 4'. The gross drainage pattern is integrated, and dominated by a single meandering stream channel; low-order drainage is a poorly developed collinear pattern. The surface configuration is undulating with ridges preferentially oriented roughly parallel to the meandering channel. The local relief rarely exceeds 10 ft, and is in most instances less. The predominant slopes are less than 5%; however, the banks of the through-flowing stream, which subdivides this region into noncontiguous segments, exhibit slopes up to 60%, and a height above low-water level of about 25 ft. Gullies are rare, but where present they are V type with fairly steep gradients. The original vegetation was probably dense forest. The region is at present almost entirely cultivated, but with rows of dense tree cover along both banks of the through-flowing stream. Roads avoid this region wherever possible. Where roads must cross the region, they tend to do so at close to right angles on causeways and bridges.
- e. Region 5'. The gross drainage pattern is a complex association of nonintegrated swallow-hole and poorly developed dendritic. Some low-order patterns are crudely pinnate, but most are dendritic. The surface configuration is

chiefly rolling and basined, or rolling and valleyed, with a tendency for the topographic highs to be more crested than in Region 1'. Local relief is generally less than 100 ft. Slopes are chiefly less than 30%, but may reach 60% in small isolated areas. Gullies, although not common, are more numerous than in the other regions of this area, and tend to be V type with relatively steep gradients. The original vegetation is indeterminate, but was probably dense forest. The region is almost entirely composed of rectangular or polygonal fields, with only an occasional small wooded area. The roads are sinuous, and tend to avoid wooded areas.

Steps 11, 12, and 13

698. Matching the properties listed for each region with the characteristics described in tables 4 through 10, it is now possible to make a determination of the probable nature of the parent materials, and from this to classify the regions into appropriate landscape types. From this, an estimate of soil types can be made. These determinations, plus the expectable associated features, are as follows:

- a. Region 1'. The parent material is massive, nearly flat-lying limestone. The associated relief results in a classification as a limestone plain. From data in Appendix B and the landscape description in Part VI, the soils on the topographic highs can be expected to be either CL or ML, and those on the topographic lows to be CL. The soils are probably fairly thick (i.e. 4 to 5 ft), because this area has undergone a long period of development and erosion under humid conditions. The photo tones should be uniform and smooth, except for the bottoms of the basins; at least a few of those which contain no water should be lighter in tone than the surrounding slope. Others should exhibit a "target" pattern with a dark outer ring at the base of the enclosing slopes. There should be a few very short gullies leading to a few of the basins; they should be of a type intermediate between V type and C type.
- b. Region 2'. The parent material is massive, nearly flat-lying limestone, possibly with some thin beds of shale or sandstone included. The associated relief results in a classification as a limestone plain. From Appendix B and descriptions in Part VI, the soils can be expected to be CL or ML. However, it should be noted that the scattered cultivated fields are chiefly, but by no means universally, on slopes that are somewhat gentler than those covered by forest. The lack of rigid control of cultivation by slope suggests that the critical factor is either soil type, soil

thickness, or both. Since cultivation requires a soil that is free of large rocks or boulders, the pattern of cultivation implies that at least some of the steep slopes in this region will exhibit soils deep enough to plow. They would be expected to be from 2 to 3 ft thick. However, the slopes will also be subject to some surface wash, and there should therefore be a few scattered outcrops of bedrock. These should be visible as light-toned flecks in a few places where bare rocks occur at the surface, or as dark flecks where shrubs have grown over bedrock so close to the surface that plowing is impossible. The wooded slopes probably exhibit very thin and discontinuous soil cover. The tree cover will make interpretation difficult, but in at least a few places very light-toned flecks from bare rock surfaces should be visible through the trees.

This region occurs in some places immediately below areas of Region 3'. The inclusion of sand from the weathering of the sandstone composing Region 3' (see description of Region 3', below) will very probably result in soils somewhat coarser grained than those of Region 1'. They may in fact be SM or SC in those areas just below areas of Region 3'. The steep slopes also suggest some surface drainage. Therefore, there should be at least a few gullies, probably crudely V type, and perhaps a few short valleys debouching into basins. The bottoms of the gullies may be somewhat "stepped," but this may not be visible at the scale of photography (1:20,000) used here.

- c. Region 3'. The parent material is sandstone, probably with interbedded shales and limestones. In climates of this type, sandstones frequently form sharply defined escarpments. The escarpments exhibited in this region are very subdued, suggesting that the sandstone is thin bedded, or poorly indurated, or both. The associated relief results in a classification as a sandstone plain. From Appendix B and the description in Part VI, the soils on the gentler slopes are probably several feet thick, with SM or ML types dominating the upper 6 in., and SM or CL types below. The latter are probably finer grained (i.e. siltier) than the surface soils. The soils on the steep slopes are probably thin and discontinuous. Such slopes should exhibit a texture of light-toned flecks, but these will be difficult to see through the tree cover. V-type gullies with steep gradients should be fairly common, and some of them may exhibit "stepped" profiles in response to the assumed bedding.
- d. Region 4'. The region is a floodplain. The nature of the parent materials in the adjacent regions suggests that the parent materials in the floodplain are dominantly fine grained, with some sand, but little or no gravel. Since it is in an early stage of development, natural levees,

abandoned courses, and well-developed backswamps cannot be expected. The difference in elevation between low-water stage and the floodplain surface implies that in this instance the plain may exhibit the features of high-level floodplains. Gullies should therefore be relatively common. The silty and slightly sandy parent materials assumed for this region should exhibit basically V-type gullies, probably much more subdued in appearance than would be true in predominantly sandy soils. From Appendix B and the description in Part V, the soils on the ridges are probably CL or CL-ML, while those in the swales are probably CL or ML, with a slightly higher proportion of silt and organic materials than those on the ridges. They are probably 2 to 4 ft thick. Considering the season of photography (August), the probable internal drainage (fair to good), and the local relief (25 ft to the river level), the soils will exhibit but slight differences in tone between ridge and swale. However, the slightly higher organic content of the soils in the swales should photograph somewhat darker than the ridge soils. The side slopes of the drainageways should be somewhat lighter in tone than the surrounding areas, due to partial loss of the slightly organic A-horizon by sheet or rill erosion.

- e. Region 5'. This region is somewhat anomalous. It exhibits the basined surface of a limestone plain, but the gullying and flecked textures of a sandy parent material. These characteristics can be reconciled by hypothesizing a thin, unconsolidated sandy stratum overlying massive limestone. The position of these areas (adjacent to the through-flowing stream and near the mouths of tributary valleys) suggests that this condition can be explained as areas of residual sandbars formed when the trunk stream flowed at a much higher level. This region could therefore be classified as a highly modified terrace. This combination would suggest sandy soils (i.e. SM or SW) on the topographic highs. These soils would accumulate larger and larger proportions of fines downslope, because of the contribution of the underlying limestone. Such soils would probably be SC, CL, or very silty SM.

Step 14

699. If the classification of landscape type and parent material is correct, then most if not all of the features listed under each regional category in step 10 should be evident. Close examination of figs. 59, 61, and 63 reveals most of them, as follows:

- a. Region 1'. The smooth textures and uniform tones are evident in both figs. 61 and 63. In figs. 62-63, a group of

basins with light-toned floors is illustrated at point A, and another group of basins illustrating the "target" appearance is at point A in figs. 60-61. That portion of figs. 58-59 classified as Region 1' remains somewhat anomalous. However, the characteristics displayed might be accounted for by assuming a relatively thin limestone stratum underlain by a thick sandstone series. The typical basins have formed, but they are neither as deep nor as well developed as is the case in the thicker limestones underlying Region 1' elsewhere. This slight variation in developmental history probably has not altered the soil formation appreciably. However, the exceptionally light tone displayed by this area suggests that internal drainage is even more rapid and complete than in areas of Region 1' elsewhere. The topographic position and the underlying sandstone probably both contribute to this effect.

- b. Region 2'. The light-toned flecks in the cleared areas are illustrated at points marked C in figs. 58-59. Such flecks are more difficult to detect in the forested areas, but they are illustrated near point D in figs. 58-59.
- c. Region 3'. The light-toned flecks are evident almost everywhere. A group of relatively poorly developed V-type gullies is present near point E in figs. 58-59. The expected "stepped" profiles are not apparent, but this may be due to the small scale.
- d. Region 4'. Gullies are very poorly developed, and the few that are present are concealed by trees, as at point A in figs. 62-63, so that their shape cannot be determined with certainty. The expected light-toned fringe is present in a few places. The swales are not noticeably darker than the ridges, except at a very few places, such as at point B in figs. 62-63. This suggests that the swale soils are not appreciably more organic or wetter than those on the ridge.
- e. Region 5'. The expected light-toned topographic highs are present in several places, notably around point C in figs. 62-63. However, the tonal variations between topographic highs and lows are much less obvious than would be expected, suggesting that the soils in the lows are not appreciably more organic or less well drained than those on the highs. The flecked texture is evident almost everywhere. In some places there are markedly V-type gullies with steep gradients, as at point D in figs. 62-63.

Step 15

700. In general, the search for supporting characteristics has tended to confirm the nature of the parent materials and soil types established in step 12. The soil types can therefore be accepted, and soil

trafficability characteristics established. Refinement of boundaries on the basis of soil variations is not necessary.

Step 16

701. The trafficability of the five regions thus far established can now be estimated from Appendix B, and the appropriate description in Parts V and VI. In general, of the possible soil types, the least trafficable is used for estimates of soil trafficability, unless specific evidence is available to permit precise identification of trafficability characteristics. In the regional descriptions that follow, the RCI given is the minimum value that occurs during the wet season. The values for the five regions thus far identified are as follows:

- a. Region 1'. The minimum RCI on both the topographic highs and lows is about 125.
- b. Region 2'. For the areas immediately adjacent to and topographically lower than areas of Region 3', and for the areas adjacent to portions of Region 3', the minimum RCI on both topographic highs and lows is about 125. The two variants found in this region are so similar that it is impractical to attempt a separation.
- c. Region 3'. No data are given in Appendix B for SM or CL soils occurring in sandstone plains. It is estimated that for SM soils found in humid sandstone plains the minimum RCI on the topographic highs is about 140, and on the topographic lows about 45.
- d. Region 4'. The minimum RCI on the topographic highs is about 60, and on the topographic lows about 35.
- e. Region 5'. The minimum RCI on the topographic highs is about 140, while the minimum on the topographic lows is about 45. The value of 140 was chosen for the topographic highs because it represents the SM soil, which is the least trafficable of the two possible soil types. In steps 11 and 12 it was assumed that the soils in the topographic lows were not organic, and that internal drainage was good. As in Region 3', the RCI for the SM soil is estimated to be 45.

Steps 17, 18, and 19

702. The final determination for trafficability purposes is to estimate the probable nature of the nonsoil obstacles to movement. With the

exception of slope, these can only be described qualitatively. It should be noted that the regions thus far erected have been defined entirely on the basis of gross topographic configuration and soil type. It is therefore possible that it will be necessary to erect subregions on such bases as the nature of the microrelief, the presence of vegetation of certain types, or other factors. Any one or all of these may affect terrain trafficability in some fashion. Accordingly, each of the five regions is re-examined, and a detailed description of the obstacles present in each is made.

- a. Region 1'. There are no detectable microrelief features except drainage ditches, cut or fill banks along the roads and railroads, and the rare and very short gullies. Most tracked vehicles could negotiate most if not all of these, but wheeled vehicles would find them impassable without engineering effort in many places. However, most such obstacles could be avoided by short detours. There are also a few very steep-sided basins, but they are of limited extent and could be readily avoided.

There are many small enclaves of woodland. Most are small enough to be readily avoided, but a few are extensive enough to constitute a serious obstacle. In general, the trees are probably large enough to stop any vehicle. They are so widely spaced that all military vehicles could thread a way between the trunks, but the resultant path length would be materially increased and speed would be reduced. The wide spacing of the trees suggests that shrub growth is relatively dense; such growth will make observation difficult and will impede movement to some extent. The variation in terrain trafficability caused by the woodland vegetation is significant enough to warrant the erection of another region. Accordingly, Region 1' is subdivided into Region 1'a, which is that portion of Region 1' that is essentially free of trees except for scattered groves or rows, and Region 1'b, which is that portion of Region 1' that is primarily wooded. This division is illustrated in figs. 64, 65, and 66.

- b. Region 2'. In this region there is a marked difference in mean slope between the wooded and cultivated areas. It has been established that there will be many rock outcrops on the steep slopes. This being the case, the surface is almost surely "stepped" as the result of slight differences in the erosion resistance of the various beds of rock. These "steps" are normally from 6 to 18 in. high. Such a microconfiguration of the surface will be very difficult, if not impossible, for wheeled vehicles to negotiate. It will be difficult for tracked vehicles, and will result in

abnormal amounts of damage to tracks and suspension systems. In addition to the differences offered by the microrelief of the surface, the relatively dense tree cover will further impede vehicular movement in this area. Accordingly, Region 2' is divided into two subregions: Region 2'a is that portion without extensive tree cover, and Region 2'b is that portion with tree cover.

The areas immediately below areas of Region 3' are probably of a different soil type, as intimated in paragraph 698b. These soils are probably discontinuous, occurring only as patches on the bedrock. They are neither thick enough nor extensive enough to significantly affect vehicle movement. This distinction is therefore irrelevant for trafficability purposes, and such areas are not differentiated.

The only significant obstacles in Region 2'a will be roadside ditches, and banks created by cuts and fills along roads and railroads.

- c. Region 3'. In this region there is no marked difference in mean slope between wooded and cleared areas. The presence of the dense tree cover, however, significantly affects movement, and this region is accordingly subdivided. The only significant obstacles in Region 3'a, the cleared portion of Region 3', are the ditches, cut banks, and fill banks beside roads and railroads, and the occasional gullies. The latter are extensive enough in some places to make relatively long detours necessary, although they can be avoided in most places. The occasional patches or rows of trees can also be readily avoided.

The dense tree cover in Region 3'b makes vehicular movement circuitous, although most military vehicles could probably thread their way through. The shrubs in the forest will probably impede visibility, thus making path selection difficult. On the steeper slopes, the surface is probably "stepped," with the features rising 6 to 18 in. above the general surface. In such places, movement will be very difficult, as described in paragraph 702b.

In a few places there are escarpments that vehicles probably cannot negotiate. These are indicated by a ticked line in figs. 64, 65, and 66.

- d. Region 4'. In this region the only obstacles will be an occasional gully, which can be easily avoided in most cases. The few patches of woodland do not constitute a significant obstacle. However, the banks of the through-flowing stream are too steep to be climbable in most places; this, coupled with the deepwater barrier of the stream itself, constitutes a generally impassable obstacle. However, careful reconnaissance would probably reveal a few places where the banks are climbable, and possibly where the water is

shallow enough for at least some military vehicles to ford. The water barrier is illustrated in fig. 66 by a line ticked on both sides.

- e. Region 5'. This region is almost completely cultivated. The only significant obstacles are ditches, cut banks, and fill banks along roads and railroads, and the steep-sided gullies. Most of these can be avoided, but the resulting detours may be extensive in many places. The occasional patches or rows of trees can generally be easily avoided.
- f. Region 6'. All major areas of varying terrain trafficability have now been described. However, one variant, the towns, which covers a relatively small area, is not included. The obstacles present in towns are so different in kind and degree that urban areas must be differentiated as independent trafficability regions. Accordingly, the urban areas are separated, and named Region 6'. They are characterized by many ditches, cut banks, walls, and other obstacles, including trees, utility poles, buildings, and various other constructions. In general, the only trafficable routes through such areas are along established roads; the directions of movement are therefore severely channeled.

Step 20

703. With these data, it is now possible to tabulate the terrain trafficability characteristics of each region, as illustrated in table 12. It should be noted that each region exhibits a slightly different assemblage of factor values, so that each region is slightly different in terrain trafficability characteristics.

Step 21

704. With these data, it is now possible to construct a terrain trafficability map of the study area. Table 12 is in effect the legend of such a map. The finished map, at a scale of 1:95,000, is illustrated in fig. 67. Maps of significantly larger scales, and therefore capable of showing much greater detail, are also possible. Figs. 64, 65, and 66 are such maps covering detailed study areas A, B, and C, respectively.

PART IX: CONCLUSIONS AND RECOMMENDATIONS

705. On the basis of discussions presented herein on estimating trafficability of soils from airphotos, the following conclusions are offered:

- a. The airphoto approach provides a means of estimating trafficability of soils when ground access is denied.
- b. Additional research, however, is required in many areas that deal with procedures and techniques for extracting precise informational content of photographs and means of expressing this information in more quantitative terms for soil trafficability purposes.

706. It is recommended that:

- a. Future work include the development of a system of terminology for describing surface configuration in a fashion suitable for photo interpretation.
- b. Further study be made of the nature and type of information that can be derived from a photograph alone.
- c. A major effort be directed toward quantifying terrain descriptions, especially descriptions of the surface configuration.
- d. A determined effort be made to develop a site classification system for photo interpretation, especially with respect to soil moisture.
- e. Work continue on the development of a soil classification scheme specifically for trafficability purposes.
- f. Effort be directed to the development of a regional concept suitable for trafficability programs.

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Navy Dept, Washington, D. C.		<u>St., N. W., Washington 6, D. C.;</u>	
ATTN: Code 70		<u>and Office of Naval Research</u>	
Coastal Studies Institute, LSU,	1	<u>(Code 493), Navy Dept.,</u>	
Baton Rouge 3, La.		Washington, D. C.	
1st Medium Anti-Aircraft	1		
Missile Battalion, Marine			
Corps Training Center,			
Twenty-nine Palms, Calif.			

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Laboratories (USASEL), Tech		Ch Signal Off, Engr & Tech Ser	1
Reports Library		Prof. Parker D. Trask, Univ of	1
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Eustis, Va.		Ch of Ordnance, Dept of Army	1
Armed Services Tech Infor Agency	10	The Pentagon, Washington, D. C.	
Arlington Hall Station		ATTN: Research & Dev Div ORDTW	
Arlington, Va., ATTN: TIPCR		Research Analysis Corp.	1
Lockheed-Georgia Co.,	1	Bethesda 14, Md., ATTN: Library	
Dept. 72-42, Zone 13, Marietta,		Commanding Office, Detroit	1
Ga., ATTN: V. Frisby		Arsenal (ORDMC-RRL), Ordnance	
Mr. T. B. Pringle, OCE	1	Corps, 1501 Beard, Detroit 9,	
New York University, College of	1	Mich., ATTN: Land Locomotion	
Engr., Research Div, Univ		Laboratory	
Heights, New York 53, N. Y.		Commandant, Command and General	1
The Chief Signal Officer	1	Staff College, Fort Leaven-	
ATTN: SIGGE-M-3		worth, Kansas, ATTN: Archives	
Radar & Meteorological		MIT, Soil Engineering Library	1
Br, Washington 25, D. C.		Cambridge, Mass.	
Chief, Office of Transportation	5		
Washington, D. C.			

LIST A (Continued)

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Director, California Forest and Range Experiment Station, P. O. Box 245, Berkeley 1, Calif., ATTN: Jack R. Fisher, Physical Scientist	1	Library of Congress, Documents Expediting Project, Washington 25, D. C.	3
U. S. Geological Survey, Military Geology Branch, Room 4225, GSA Bldg., Washington 25, D. C.	1	Cdr., Ordnance Weapons Command, Rock Island, Ill., ATTN: ORDOW-OR	1
Davidson Laboratory, Stevens Institute of Technology, 711 Hudson St., Hoboken, N. J.	1	National Tillage Machinery Lab., U. S. Dept. of Agriculture, Auburn, Ala.	1
Commanding Officer, Ordnance Test Activity, Yuma Test Station, Yuma, Ariz., ATTN: Automotive Reference Library	1	Engineering Societies Library, 345 E. 47th St., New York 17, N. Y.	1
Office, Quartermaster General, Dept. of the Army, Washington 25, D. C., ATTN: Res & Engr Div, Devel Br	1	Chief, Research & Development, DA, ATTN: Chief, Combat Materiel Div., Washington 25, D. C.	1
Mr. David Cardwell, Asst Dir, Basic Res Fighting Vehicles R&D Estab, Chobham Lane, Chertsey, Surrey, England (ENG-238)	1	Library, Division of Public Documents, US Government Printing Office, Washington 25, D. C.	1
Mr. A. O. Barrie, Ministry of Supply, Mil Engr Experimental Estab, Barrack Road, Christchurch, Hampshire, England (ENG-240)	1	Martin Company, Orlando, Fla., ATTN: W. A. Headley, Jr., Technical and Research Staff, Mail No. MP-28	1
Dr. William Lucas Archer, Scientific Res Off., Canadian Army Oper Res Estab, Canadian Army Hq, Ottawa, Canada (ENG-239)	1	Commanding General, U. S. Army Transportation Combat Dev Group, Ft. Eustis, Va., ATTN: Earl S. Brown	1
U. S. Army Map Service, Far East APO 94, San Francisco, Calif., ATTN: Area Analysis Division	1	CO, Picatinny Arsenal, Dover, N. J., ATTN: Mr. R. G. Thresher	1
Mr. John Lewis Orr, Dir of Engr Res, Canadian Army Operational Res Estab, Defence Res Board Ottawa, Canada (ENG-242)	1	Schuel Feltman Ammunition Labs. Ammunition Research Lab. Engineering Research Section	1
Heavy Construction Section Dept. of Engineering Pavements & Materials Group, US Army Engr School, Ft. Belvoir, Va., ATTN: Raymond Hansen	1	Caterpillar Tractor Company, Peoria, Ill., ATTN: Research Library	1
		CO, Rock Island Arsenal, Rock Island, Ill., ATTN: Bill Heidel 9310-AR	1
		Chief, Terrain Detachment, Engineer Section, Hq., Fourth U. S. Army, Fort Sam Houston, Tex.	1
		Defense Systems Division, General Motors Corporation, Box T, Santa Barbara, Calif. ATTN: J. P. Finelli	1

LIST A (Continued)

Special (Continued)

Meteorology Res Div, Meteorology Dept., US Army Electronic Prov- ing Ground, Fort Huachuca, Ariz., ATTN: SELHU-MM	1	University of Arkansas College of Engineering ATTN: Mr. Henry H. Hicks, Jr. Fayetteville, Ark.	1
University of Mich. Research In- stitute Automotive Lab., Ann Arbor, Mich.	1	President, US Army Transportation Board, ATTN: TCTCB-EN, Fort Eustis, Va.	1
Clark Equipment Company, Construction Machinery Div. Pipestone Plant Benton Harbor, Mich.	1	Chief of Research & Development, DA, ATTN: Dr. L. S. Wilson, Washington, D. C.	1
Chief of Transportation, DA, ATTN: Mr. R. C. Kerr, Chief Scientist, Washington 25, D. C.	1	Chief of Transportation, DA, ATTN: TCDTE, Mr. C. H. Perry, Deputy Director of Transporta- tion Engineering, Washington 25, D. C.	1
CG, US Army Transportation Re- search Command, ATTN: Lt. Col. R. W. Wildey, Ft. Eustis, Va.	1	Commandant, USA Transportation School, Ft. Eustis, Va.	1
Prof. L. C. Stuart, University of Mich., Ann Arbor, Mich.	1	Chief, Research & Development, DA, ATTN: Chief, Earth Sciences Div., Washington 25, D. C.	1
CO, US Army Ordnance Tank- Automotive Command, ATTN: ORDMC-RRL, Mr. R. A. Liston, 1501 Beard, Detroit 9, Mich.	1	Library, National Research Council, Ottawa, Canada (ENG-17)	1
Mr. Seth Bonder, Project Super- visor, Ohio University Engineer- ing Experiment Station, 159 West 19th Avenue, Columbus 10, Ohio	1	Commander, US Strike Command, ATTN: J4-T, McDill AFB, Fla.	1
Engineer Intelligence Center, Office of the Engineer, ATTN: Mr. Gerald M. Goldberg, USAREUR, APO 403, New York, N. Y.	1	Prof. R. D. Miles, Research Engi- neer, Airphoto Interpretation Laboratory, Engineering Ex- periment Station, Purdue University, Lafayette, Ind.	50

U. S. Air Force

Hqs, USAF, DC/S Operations, Director of Operations, Operations & Commitments Division (AFOOP-OC-S) Washington 25, D. C.	1	Cdr, MATS, Andrews AF Base, Washington 25, D. C. ATTN: Air Installations Off	1
Hqs, USAF, DC/S Devel, AFDRQ - Command Support Div, Washing- ton 25, D. C.	1	Hqs, USAF, DC/S Devel, AFDRD - Equip Div, Washington 25, D. C.	1
Cdr, Wright Air Devel Center, ATTN: WCLEI, Air Installations Br., Equipment Laboratory	1	Cdr, Air Prvg Gr Command, Eglin Air Force Base, Fla., ATTN: PGAPT	1
Cdr, Maxwell AF Base, Ala., ATTN: A-2 Library	1	Cdr, Wright Air Devel Center, Wright-Patterson AF Base, Ohio, ATTN: WWDPFE	1
		Installations Engr School USAFIT, Wright-Patterson Air Force Base, Ohio	1

LIST A (Continued)

U. S. Air Force (Continued)

Cdr, Maxwell AF Base, Ala.,	1	Terrestrial Sciences Laboratory,	3
ATTN: Research Section		CRZG, AF Cambridge Res Labs.,	
Cdr, Air Res and Dev Command	1	L. G. Hanscom Field, Bedford,	
P. O. Box 1395, Baltimore 3, Md.		Mass., ATTN: Mr. C. E. Molineux	
ATTN: RDTDE, Equipment Division			

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REPORTS OF THE SERIES ENTITLED "TRAFFICABILITY OF SOILS"
TECHNICAL MEMORANDUM NO. 3-24

Supplement No.		Date
	Pilot Tests--Self-propelled Vehicles	Nov. 1947
1	Laboratory Tests to Determine Effects of Moisture Content and Density Variations	Mar. 1948
2	Trafficability Studies, Fort Churchill, Summer 1947	Aug. 1948
3	Development of Testing Instruments	Oct. 1948
4	Tests on Self-propelled Vehicles, Yuma, Arizona, 1947	Apr. 1949
5	Analysis of Existing Data	May 1949
6	Tests on Self-propelled Vehicles, Vicksburg Miss., 1947	Sept. 1949
7	Tests on Towed Vehicles, 1947-1948	June 1950
8	Slope Studies	May 1951
9	Vehicle Classification	May 1951
10	Tests on Natural Soils with Self-propelled Vehicles, 1949-1950	Jan. 1954
11	Soil Classification	Aug. 1954
12	Tests on Natural Soils with Self-propelled Vehicles, 1951-1953	Nov. 1954
13	Pilot Study, Tests on Coarse-Grained Soils	Nov. 1955
14	A Summary of Trafficability Studies Through 1955	Dec. 1955
15	Tests on Coarse-Grained Soils with Self-propelled and Towed Vehicles, 1956 and 1957	June 1959
16	Soil Classification	Aug. 1961
17	Tests on Coarse-Grained Soils with Self-propelled and Towed Vehicles, 1958-1961	May 1963